Interchangeable Parts: An Examination and Comparison of Fixed and Modular Trombones

Gabriel Andrew Rozsa

McGill University
Schulich School of Music
Montréal, Québec, Canada
December 2014

A paper submitted to McGill University in partial fulfillment of the requirements of the degree of Doctor of Music in Performance Studies

Contents

Abstract

For most of the 20th century, trombonists have been limited to a few mass-produced instruments that, while generally of high quality, do not always fit each player or situation well. Players seeking to "fine-tune" their trombones often were forced to seek expensive and unpredictable custom modifications. Also, trombonists performing in widely different musical styles and performance settings often own a number of different instruments, each suitable for different situations (i.e. classical vs. jazz).

Recently, a number of boutique trombone manufacturers have emerged, offering modular trombones as a solution to both problems. These instruments are designed with interchangeable bells, slides, valves, tuning slides, and leadpipes, which can quickly and easily be exchanged with other parts of different designs, materials, or both.

This thesis examines a number of traditional (fixed) and modular trombones with two objectives. The first objective is to determine if certain combinations of modular trombones could be used to adequately emulate the sound and feel of the fixed trombones they are based on. The second objective is to examine ways in which the performer might use different modular parts to tailor their sound to their specific musical needs and aesthetic preferences.

The results show that both bore size and bell design do have considerable influence on the resultant sound and feel of a trombone to the player and listener, and by selecting modular trombones with bell designs and bore sizes that match those of fixed trombones, a player is able to adequately emulate those instruments. Also, the modular trombone setup, by allowing a wider range of equipment configurations, is shown to enable the performer to more finely tune their sound to the needs of each individual work.

Abrégé

Pour la majeure partie du 20e siècle, les trombonistes ont été limité à un nombre restreint d'instruments, tous produits à la chaîne. Quoique généralement de haute qualité, ces instruments ne correspondaient pas toujours précisément à chaque musicien ou chaque situation. Les trombonistes qui désiraient avoir un trombone adapté à leurs besoins étaient forcé d'effectuer des modifications coûteuses et imprévisibles. Également, les trombonistes qui voulaient jouer dans des styles variés de musique ou dans des circonstances divergentes devaient posséder plusieurs instruments, chacun étant utilisé pour un style en particulier (ex. classique vs. jazz).

Récemment, plusieurs fabricants de trombone ont fait leurs apparitions, offrant des trombones modulaires comme solution aux deux problèmes. Ces instruments sont construits avec des parties interchangeables comme la cloche, la coulisse, le barillet, les coulisses d'accords et la branche d'embouchure, qui peuvent être facilement échanger avec d'autres parties soient construits différemment, construit avec un matériel différent ou les deux combinés.

Cette thèse examine quelques trombones traditionnels (fixe) et modulaire avec deux objectifs. L'objectif premier est de déterminer si certaines combinaisons de trombone modulaire peuvent imiter le son et la sensation des trombones fixes sur lesquels ils sont basés. Le second objectif est d'examiner les façons dont l'interprète peut utiliser des parties modulaires différentes pour façonner le son pour leurs besoins et leurs préférences esthétiques.

Les résultats montrent que les deux dimensions de l'alésage et la conception de cloche ont une influence considérable sur le son qui en résulte et la sensation d'un trombone au lecteur et auditeur, et en sélectionnant trombones modulaires avec des dessins de cloche et alésages qui correspondent à ceux de trombones fixes, un joueur est capable d'émuler de façon adéquate ces instruments. En outre, la configuration de trombone modulaire, en permettant à un plus large éventail de configurations d'équipement, est indiqué pour permettre à l'interprète de plus de régler finement leur son aux besoins de chaque travail individuel.

Acknowledgements

First, I would like to thank my teachers, James Box and Pierre Beaudry, for years of lessons and feedback. I would also like to acknowledge my previous teachers: Doug Bennett, Dan Adams, Allen Kofsky, Thomas Klaber, Charles Vernon, Mark Fisher, and Floyd Cooley. I never would have made it to this point without your guidance.

None of the technical analysis would have been possible without the invaluable assistance of Dr. Gary Scavone, who graciously allowed me access to the CIRMMT labs, as well as his invaluable expertise in the areas of acoustics, programming, and instrument design.

I would also like to acknowledge Dr. Eleanor Stubley, the head of my doctoral committee, for pushing me when I needed it, but also for listening to my concerns and offering honest and valuable advice along the way.

Thanks to my fantastic accompanist, Katherine Petersen, for years of musical partnership and patience with the difficult subject matter that is bass trombone solo literature.

A number of people were kind enough to allow me to use their instruments for testing and demonstration, including: Maximilien Brisson, Thomas Burton, Sarah Carbonneau, Raymond Carruthers, Aaron Chan, Taylor Donaldson, Alexis Grant-Lefebvre, Ann-Merrie Leung, Isabelle Lavoie, David Leroux, David Martin, Hillary Simms, and Alex Truelove. Also, special thanks to Sarah Carbonneau for the excellent video recording of my lecture-recital.

I would like to thank Camille Renaud for her assistance with French translations.

Assisting me in locating the proper bell mounting hardware were Brian Russell of Russell Winds and Graham Middleton of the Schilke Corporation. I also would like to thank Michel Bathalon of Twigg Music for his excellent work installing this hardware on each bell.

Finally, I wish to thank my wife, Anne-Marie, and our son, Simon, for patiently supporting me throughout this long process. None of this would have been possible without your love and understanding.

Introduction

Since its invention, the trombone has been called on to fill a number of different musical roles; the symphony orchestra, military band, solo music, chamber music, and jazz all make extensive use of the trombone.[1] The sonic and practical requirements for each of these roles are different enough that performers usually choose their trombone based on the needs of their primary musical genre. For example, today's orchestral trombonist generally prefers to use a large-bore, large-bell instrument for its stable tone, secure intonation, and ease of projection, while the jazz trombonist typically chooses a smaller instrument more suited for flexibility and ease in the high register.[2]

During the first half of the 20th century, instrument makers such as Vincent Bach and C.G. Conn began mass-production of a small number of trombone designs, each geared toward different musical needs. Of course, the modern trombonist rarely stays within the confines of one genre – it is quite common for even major symphony orchestras to play "pops" shows which branch out into jazz, film, and rock idioms.[3] Even if one managed to completely avoid non-classical repertoire, classical solo and chamber music now utilize trombones far more often than before,[4] and they have their own different sonic requirements, often borrowing from jazz.

Furthermore, as a result of improved scholarship, the classical realm has itself expanded. For certain works, such as the Mozart *Requiem,* the Haydn *Creation*, and the symphonies of Beethoven, Schubert, and Schumann, orchestral trombonists will sometimes use smaller instruments to more closely match the sound the composer was familiar with.[5]

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[1] Ahrens, p.36, 47; Guion p.185, 192
[2] Wick, p.1-3
[3] Guion, p.203
[4] Guion, p.192-197; Wick p.87
[5] Wick, p.93-95; Bulen, p.112-113

This has left the trombonist with two options: they could own multiple instruments, each selected for a specific situation and sound quality, or they could adjust their performance practice on their existing instrument in an attempt to imitate the desired sound. While owning multiple instruments might seem ideal, considerations of transportation and storage often render this impractical – to say nothing of the difficulty in learning to play many different trombones, each with different response, intonation, grip, and weight.

The second option – performance practice adjustment – is the simplest and the most common solution. In this approach, the performer uses one trombone, performing music of all styles on it. In order to perform different styles more accurately, the player may alter their articulation, air delivery, and tongue position. For instance, a bass trombonist playing jazz on a large-bore symphonic instrument might use a stronger articulation with a slightly narrower airstream in the lower range to recreate the bright, "edgy" sounds of a jazz bass trombone.

This solution also has its drawbacks, as it tends to physically tax the performer, while delivering results that often do not sound authentic. In either case, a professional trombonist today will typically own one "primary" instrument that they perform most styles of music on, perhaps with one or two additional instruments of different designs for "specialty playing" or "doubling."

For most serious instrumentalists, picking out a professional-quality instrument is a personal process, often involving working with instrument designers and play-testing dozens of existing instruments before settling on one in particular. For the past 80 years, however, trombonists have been limited to a few specific, mass-produced designs when picking their primary trombone, often resorting to expensive and unpredictable custom modifications if the default setup is not satisfactory.

In recent years, a number of small, "boutique" trombone manufacturers have emerged, offering what seems to be an ideal solution for all of these issues: the modular trombone. With interchangeable bells, slides, valve sections, leadpipes, and tuning slides, these trombones allow the player to more closely customize their instrument to their needs, and even to make changes to their primary instrument without the need for permanent custom work. [6]

For instance, if the performer prefers the wide slide of a large-bore Bach 42, but the thinwall red brass bell of a Conn 88H, they could simply select modular parts that match these designs, and assemble them into one trombone. Then, if they later had a performance that sounded better and felt more comfortable on a different bell, they could simply exchange their current bell for that one.

This thesis examines a number of traditional (fixed) and modular trombones with two objectives. The first objective is to determine if certain combinations of modular trombones could be used to adequately emulate the sound and feel of the fixed trombones they are based on. The second objective is to examine ways in which the performer might use different modular parts to tailor their sound to their specific musical needs.

[6] http://www.edwards-instruments.com; http://www.seshires.com/; http://www.rathtrombones.com/

Chapter 1 – Background

1.1 Basic Information

There are three main types of trombones in use today – alto, tenor, and bass. Of those, the tenor trombone is the most common (and typically what is being referred to when just the generic term "trombone" is used.) When classifying trombones, two primary measurements are considered – *bell diameter* and *bore diameter*. (Bore diameter, in this case, refers to the inner diameter of the inner slide tube.)

The tenor trombone itself has three subcategories – "small-bore," "medium-bore," and "large-bore." Traditionally, the symphony orchestra employs two large-bore tenor trombones, one bass trombone, and one tuba, while the big band uses three small or medium-bore tenors and one bass. In orchestra and chamber contexts, the first trombonist usually "doubles" on alto trombone, rather than playing it exclusively.

Trombone Type	Bore Diameter	Bell Diameter
Alto Trombone	.480-.500 inches	7 inch
Small-Bore Tenor	.480-.500 inches	7.5 inch
Medium-Bore Tenor	.508-.525 inches	8 inch
Large-Bore Tenor	.547 inch	8.5 inch
Bass Trombone	.562 inch	9-10.5 inches

Table 1- Modern trombone bore/bell sizes, by type

While designs have varied based on time period and location, instrument builders have, in the last 80 years, settled on certain common specifications. (Table 1) Alto trombones are usually built with a 7-inch diameter bell and a bore size between .480 and .500 inches; small-bore tenor trombones will use a similar bore size, with a slightly larger 7.5 inch bell. Medium-bore tenor trombones are built with an 8-inch bell and a slide bore between .508 and .525 inches. Large-bore tenor trombones are almost universally built with an 8.5 inch bell and a .547 inch bore. Finally, bass trombones use bell diameters ranging from 9 inches to 10.5 inches, with bore sizes ranging from .562 to .580 inches.

Generally speaking, smaller bore and bell sizes are considered by players and manufacturers to be more suitable for lighter articulation, brighter tone quality, easier high register playing, and an overall more compact sound. Larger bore sizes are seen as more suitable for stable tone, projection, and an easy low register.

It is important to point out that all of the tenor and bass trombones are built with the same length and fundamental pitch – B-flat – and as such, function very much the same. (The alto trombone is keyed higher, in E-flat.) The differences in bore size and bell design are enough, however, that the instruments feel and sound quite different.

1.2 Performance Practice and Instrument Choice

When choosing a trombone, the performer is usually looking for an instrument that satisfies two criteria: first, the instrument must be comfortable, so that playing it in a way that produces a high-quality sound feels as easy as possible. Second, it should fit the musical situation and context that the performer normally expects to use that particular trombone in.

While finding an instrument that is comfortable to play is an individual process that varies widely from person to person, the historical practices that dictate which type of trombones should be used for each musical context are more well-defined. In most situations, trombonists usually gravitate towards trombones that resemble those familiar to the composer of the work being performed.

For example, trombonists that perform primarily in the symphony orchestra would usually find it easiest to play most literature on large-bore, large-bell instruments, since the vast majority of orchestral works using trombones were composed after the use of large-bore trombones in the orchestra had become the norm.

Certain pieces, however, were written and orchestrated by composers who had a widely different concept of orchestral trombone sound than what is common today. The Mozart *Requiem* is a good example. Measurements of extant trombones dating from early 19th century Vienna show significant differences from those built during the later 19th and 20th centuries[7], and this would certainly have affected the orchestration choices Mozart made.

The trombones of Mozart's day can be described in one word – tiny. The bore size of the tenor trombones of that time period averaged around .425 inches, while the bass trombones averaged around .450 inches – both about .1 inches smaller than their modern-day counterparts. The resulting sound would have been closer to that of the sackbut – thinner, brighter, softer, and more compact. Also, the first trombonist would certainly have performed on an alto trombone.

As such, Mozart would have written for the trombone in a very different way than Mahler and Stravinsky; in the *Requiem*, he calls for the alto, tenor, and bass trombones to double the alto, tenor, and bass voices of the choir for a large percentage of the work. Since the trombones he was accustomed to hearing sounded smaller and thinner than modern instruments, he would have found the sound less overbearing than on larger trombones. Trombonists using a modern, large-bore design for this work quickly find that they must reduce virtually every dynamic to *mezzo piano* or *piano* to avoid overpowering the choir.

Consequently, common practice in modern orchestras for these types of works is to "scale down" – the first trombonist plays alto, the second trombonist plays a medium-bore instrument, and the bass trombonist plays a large-bore tenor trombone, rather than an actual bass

[7] Guion, p. 64-66; Myers, p.49

trombone. (Trombone sections as varied as those of the Boston Symphony Orchestra[8], Royal Concertgebouw Orchestra[9], and the National Symphony Orchestra[10] in the United States all have recently done this.)

The use of smaller trombones is also common in jazz trombone playing. In contrast to the orchestra, the trombones used by many famous jazz pioneers are still in production today. Tommy Dorsey, J.J. Johnson, and Kai Winding all performed on and endorsed the King 2B and 3B small/medium bore trombones; consequently, they are both still in production (even though King itself is no longer in business) and are still widely used by jazz and commercial players.

1.3 Traditional (Fixed) Trombone Designs

Since the mid-1930s, two major manufactures have emerged offering a range of trombones – the Vincent Bach Corporation and the C.G. Conn Company.

The Bach Corporation was formed in 1918 by New York City trumpeter Vincent Bach. Though he only produced mouthpieces in the early years, by 1924 the company had begun producing trumpets, with trombones following in 1928.[11] Bach released its small-bore tenor trombones, the Bach 6, Bach 8, and Bach 16, the medium-bore Bach 36, and its bass trombone, the Bach 50, all between 1932 and 1938. Bach would not release its immensely popular large-bore tenor trombone, the Bach 42, until 1952.[12]

Charles Gerard Conn was a U.S. Civil War veteran, newspaper magnate, and member of Congress who opened his own trumpet mouthpiece business in 1873. By 1879, his company had begun manufacturing complete instruments. In 1915, he retired, selling the company to Carl

[8] http://www.tobyoft.com/equipment
[9] https://www.facebook.com/trombonesrco/photos/a.586881868030266.1073741827.117668144951643/671257506259368/?type=1
[10] http://craigmulcahy.com/equipment/instruments/
[11] http://www.bachbrass.com/history
[12] Guion, p.72

Greenleaf; Greenleaf expanded the operation dramatically, introducing a large variety of trombone designs, many of which are still in production today. (Table 2) Conn released the small-bore 4H, the medium-bore 6H, and the 70H bass trombone around 1940, adding large-bore tenors – the 8H and 88H – in 1954, and a double-valve bass trombone – the 62H – in 1968.[13]

Besides Bach and Conn, a few other manufacturers have contributed popular designs over the years that are still in production by their successor companies. The now-defunct King Corporation's jazz trombone line, which includes the small-bore King 2B and medium-bore King 3B, is still manufactured today by Conn, for example.

Trombone Model	Trombone Type	Year of Introduction	Bore Diameter	Bell Diameter
Conn 4H	Small-bore Tenor	1936	.485"	7"
Conn 6H	Small-bore Tenor	1937	.500"	8"
Conn 8H	Large-bore Tenor	1954	.547"	8.5"
Conn 32H	Medium-bore Tenor	1934	.500"/.522"*	7.5"
Conn 62H	Bass	1968	.562"	9.5"
Conn 70H	Bass	1940	.562"	9.5"
Conn 88H	Large-bore Tenor	1954	.547"	8.5"
Bach 6	Small-bore Tenor	1932	.485"	7.5"
Bach 8	Small-bore Tenor	1934	.490"	7.5"
Bach 16	Medium-bore Tenor	1932	.495"/.509"*	7.5"
Bach 36	Medium-bore Tenor	1932	.525"	8"
Bach 42	Large-bore Tenor	1952	.547"	8.5"
Bach 50	Bass	1938	.562"	9.5"
King 2B	Small-bore Tenor	1938	.481"	7.25"
King 3B	Medium-bore Tenor	1951	.508"	8"
King Duo Gravis	Bass	1971	.562"	9.625"

* Slide is "dual bore", meaning that the slide tubes are of different bore diameters

Table 2 - Measurements of common fixed-trombone designs

Each of these designs is still in use; the Bach 42B, Bach 50B, and Conn 88H are still widely played by symphony players, and many big-band trombonists still prefer the King 2B or Conn 62H. These designs have remained so popular that virtually every modular trombone sold

[13] http://www.conn-selmer.com/en-us/about/history/

can be assembled with parts designed to give the player the sound and feel of these "classic models."

The fixed instruments that I have measured and tested for the purposes of this document are: the medium-bore Conn 32H, the large-bore Conn 88H and Bach 42B, and the Bach 50B and King Duo Gravis bass trombones. It is important to note that, while the bore size among these instruments varies little between models, the materials and bell designs are quite different. For example, bells not only come in a number of different sizes, they are made of different metals and alloys (such as yellow brass, gold brass, red brass, and sterling silver), are made with different thicknesses of metal, and even different styles of bell rim (some manufacturers simply bend the end of the bell over a metal wire, known as a "bead," while others will actually solder the rim down after bending it to shape.)

1.3.1 Conn 32H

Figure 1 - Conn 32H Medium-bore Tenor Trombone

The Conn 32H has a 7.5 inch bell made of yellow brass with an unsoldered rim bead. The slide is what is known as a "dual-bore" slide – the first tube is .500 inches in diameter, and the second tube is a little larger, at .522 inches. This trombone is lightweight and has no valve section.

1.3.2 Conn 88H

The Conn 88H has an 8.5 inch bell made of rose brass with an unsoldered rim bead. The slide bore is .547 inches in diameter. The 88H has a distinctive valve section that places the instrument in F, to facilitate low-register playing. Though this instrument is a large-bore tenor trombone, it has a relatively light, though still rich, tenor trombone tone.

Figure 2 - Conn 88H Large-bore Tenor Trombone

1.3.3 Bach 42B

The Bach 42B has an 8.5 inch bell made of yellow brass with a soldered rim bead. The slide bore is also .547 inches and this trombone also has an F-valve. Compared to the Conn trombones, the Bach 42B has a much wider slide and is a bit heavier to hold. This instrument projects well, has a very stable sound, and can play somewhat louder than the Conn 88H without the sound breaking up; it is often more difficult to play delicately, however, particularly in the upper register.

Figure 3 - Bach 42B Large-bore Tenor Trombone

1.3.4 Bach 50B

The Bach 50B is the bass trombone version of the 42B. The bell is 9.5 inches in diameter and is made of yellow brass with a soldered rim bead. The slide is .562 inches in diameter throughout. Most 50B models have two valves in various configurations, and Bach also produces models with different bell size and alloy (the 50BG, for instance, is made from gold brass, rather than yellow brass, but is otherwise the same.) This instrument is the classic "heavy duty" orchestral bass trombone, capable of filling a concert hall without sounding "wobbly" or crass.

Figure 4 - Bach 50B Bass Trombone

1.3.5 King Duo Gravis

The King Duo Gravis is a bass trombone aimed at jazz performers. It has a sterling silver bell, 9.625 inches in diameter with a soldered rim. The slide has a .562 inch bore. The Duo Gravis also has two valves, though always in a "dependent" configuration, where the second valve only changes the key of the first valve, rather than the entire instrument. The Duo Gravis has a darker, more velvety tone than the Bach 50B, though in the louder dynamics, the sound gets bright and edgy at much lower dynamic levels.

Figure 5 - King Duo Gravis Bass Trombone

1.4 Modular Trombone Designs

Since the 1990s, a small number of "boutique" trombone manufacturers have opened their doors. In North America, three notable modular trombone shops have operated during this time: Edwards Instruments, the S.E. Shires Company, and Greenhoe Custom Instruments. Though Greenhoe ceased operations in early 2013, Edwards and Shires have maintained a large customer base that includes professional players in both classical and commercial genres.

While traditional trombones are built to disassemble only at the joint where the slide and bell section come together, modular trombones usually have screw-type connectors at the bell supports, as well as threaded leadpipes, allowing the bell, valve section, and leadpipe to all be removed and replaced without special tools.

Figure 6 - A Modular Tenor Trombone, shown with detached valve section and bell

It should be noted that the introduction of modular trombones by these smaller manufacturers has actually resulted in the larger manufacturers introducing their own modular designs. In the late 1990s, Conn updated the Conn 88H line to include removable leadpipes and numerous options for bells and slides; Bach released a fully modular tenor trombone line in 2013 with interchangeable bells, valves, leadpipes, and slides.

For the purposes of this document, however, I will focus on two specific models of modular trombones; for tenor trombones, I will examine instruments consisting of a number of parts made by Shires, while for bass trombones, I will look at a modular trombone built by Greenhoe Musical Instruments.

The modular tenor trombone equipment selected was chosen based on similarity to existing classic designs. For example, the first tenor bell, the 2RVE, is advertised by Shires as the "Vintage Elkhart" model. (Elkhart refers to Elkhart, Indiana, where the original Conn 88H was produced.) Like the bell used in the Conn 88H, it is 8.5 inches wide, has an unsoldered rim bead, and is made out of thin, red brass.

The second bell, the 7YM, is advertised as being similar to that of the Bach 42B, and like the 42B it is 8.5 inches in diameter, has a soldered rim, and is made of yellow brass.

The slides chosen have one main difference – bore size. The standard slide has the customary large-tenor bore size of .547 inches, while the second slide uses a smaller .525 inch bore. For the purposes of this comparison, the standard leadpipe was always used.

The modular bass trombone was built by Greenhoe in late 2004. It has five different interchangeable bells, most of which were originally bells removed from fixed trombones. Three of these bells have been removed from Bach 50B trombones of various designs – a standard yellow-brass Bach 50B bell, a gold-brass Bach 50BG bell, and an extra-large Bach 50BL bell, which is made of yellow brass and measures 10.5 inches in diameter, instead of the customary 9.5 inches. All three have soldered rims. Each bell was selected based on its use in actual fixed-horn designs.

The last two bells were made by Shires and retrofitted to fit Greenhoe connections; one is the 2RGLW, which is 9.5 inches wide with an unsoldered rim, similar to a Conn 62H bell, and the unique 2YHW, which is a thick-wall, heavy weight yellow brass bell also with an unsoldered rim; this has no exact equivalent among mass-production models. The 2RGLW was selected due to its similarity to the classic Conn 62H bass trombone, while the 2YHW was selected due to its unique design and weight, which is touted by the manufacturer as being easier to play at louder dynamic levels.

The two slides differ only in bore size; the standard size measures .562 inches, while the smaller slide measures .547 inches. The smaller slide was chosen in this configuration to imitate the smaller bore size of the large-bore tenor trombones often used to play the bass trombone parts of earlier orchestral works.

In Chapter 3, examples from the orchestral literature are used to show how different combinations of modular trombone equipment can be selected in ways which more adequately emulate certain fixed trombones, with an eye toward more historically accurate performances. In Chapter 4, a number of examples from the solo literature are examined, exploring the ways in which the performer might use different modular parts to tailor their sound to their own sonic and artistic preferences.

Chapter 2 – Trombone Measurement

2.1 Introduction

Evaluating any trombone involves two main considerations: the resulting sound to the listener, and the feel of the instrument to the performer. When assessing the resultant sound of a trombone, one must consider not only aspects of the actual tone quality (such as clarity of attack, or brightness/darkness of sound), but also whether or not the sound is appropriate in the musical context in which it is used.

When assessing the feel of the instrument, one must consider how easy the performer finds the basic physical maneuvers of playing the trombone (such as articulation, harmonic series slurs, maintenance of stable tone, etc.). A well-built trombone should ideally feel easy to play with a high-quality sound during most circumstances; a well-selected trombone should produce an appropriate sound for the musical context in which it is being used.

Since both feeling and listening can be highly subjective, it helps to have a method of objective measurement to back up (or contradict) a player's preferences with hard data.

Figure 7 - The BIAS System, developed by the Institut für Wiener Klangstil, Vienna, Austria, is a commercially-available input impedance measurement system. A similar system, CapteurZ from the Centre de Transfert de Technologie du Mans, France, was used to gather the measurements in this document. Note the mouthpiece shank pointing upward from the top of the testing cylinder.[14]

[14] http://orgs.usd.edu/nmm/UtleyPages/Utleyfaq/BIAS/Figure3-assembledLG.jpg

In this case, trombones were compared using measurements of *input impedance* and the transfer function of *radiated pressure to input volume velocity*. In a laboratory at McGill's Centre for Interdisciplinary Research in Music, Media and Technology (CIRMMT), each of the aforementioned modular and fixed trombones were measured for the purpose of comparing the instruments' physical vibration properties.

2.2 Input Impedance/Radiation Transfer Function Measurements

For *input impedance* measurements, the air inside the trombone is excited over the audible frequency range by a low-powered speaker inside a brass cylinder; microphones next to the driver capture the resulting response at the mouthpiece, from which details of the resonant frequencies of the instrument and their respective strengths are computed. During these tests, a small microphone was also placed over the bell, to pick up the sound coming out of the instrument; this is used to compute a transfer function of *radiated pressure to input velocity*.

When considering only the input impedance results, the result is a graph (Figure 8) that shows a series of peaks, each of which correspond to the frequency of one of the natural notes of the instrument's overtone series. The height of each peak indicates the relative strength, or amplitude, of each resonance, and the width of each peak indicates the relative damping. (Frequencies with lower damping ring longer, have narrower peaks, and usually have a greater amplitude.) The strength and placement of each resonant frequency can potentially reveal a great deal about how an instrument sounds and plays. [15]

[15] Braden, et al., p. 2404-2412

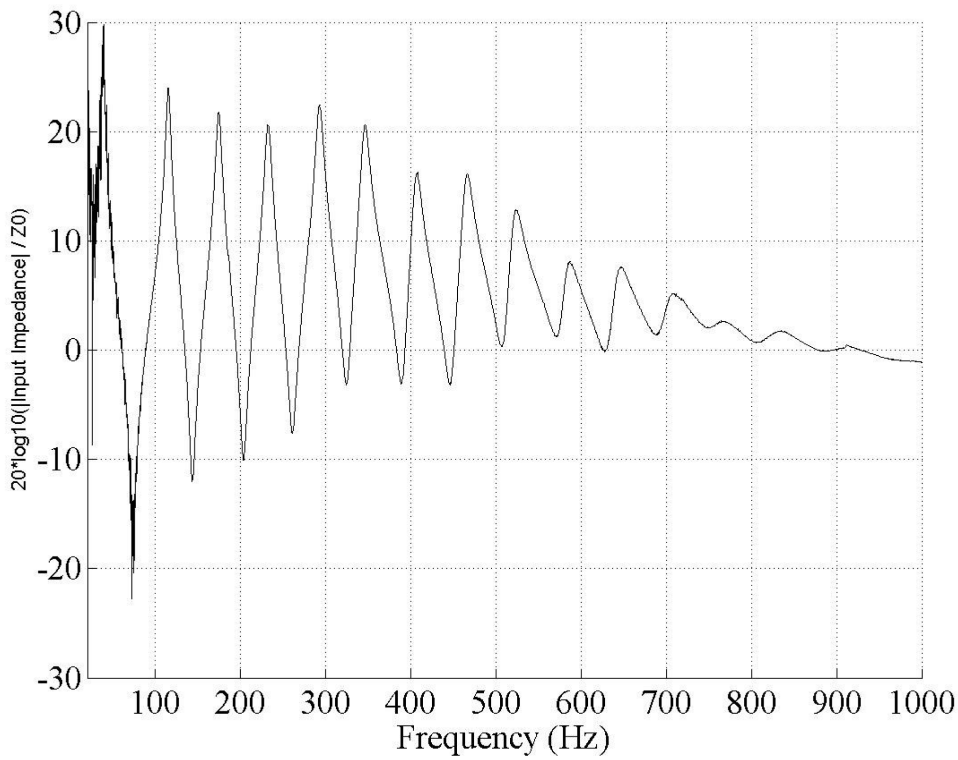

Figure 8 - Input Impedance Measurements of a Bach 50B Bass Trombone

By itself, this graph only shows at which frequencies each overtone sounds and the amplitude and damping of each. Since much of how a brass instrument feels and sounds is based on how close the frequency of each partial is to a "perfectly-harmonic series of acoustical resonances," a graph comparing the input impedance of an instrument to a mathematically-perfect harmonic series is useful.

Braden, et al. describe this type of graph as a "harmonicity plot," in which the input impedance peak frequencies are compared to those of a perfect harmonic series. In this graph, (Figure 9) two harmonicity plots are shown; one of the Conn 32H, and the other of a Bach 50B. The frequencies that form a perfect harmonic series over the fundamental of the instrument are shown with a red 'x,' while the actual resonant frequencies of the instrument are represented by blue circles.

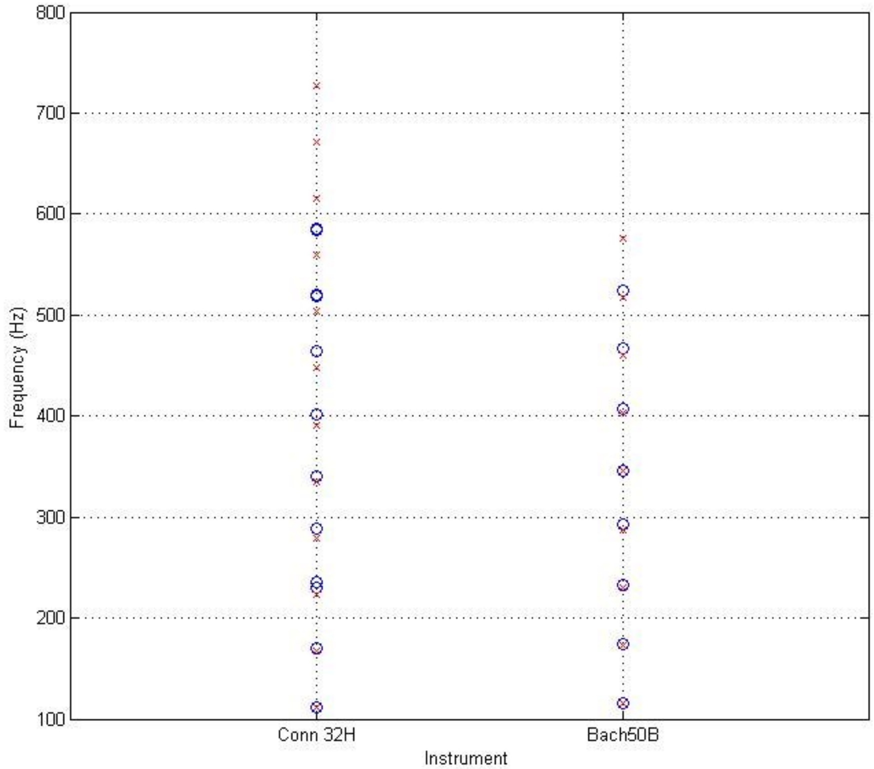

Figure 9 - Harmonicity plot showing the relationship of input impedance peaks (blue circles) to the perfectly harmonic frequencies (red)

Comparing the measurements of the Bach 50B with those of the Conn 32H is a good way to see the value in calculating harmonicity. The 32H has a significantly less perfectly-aligned second harmonic than the Bach, indicating that it will not play as easily in the lower register. [16] Also, while the upper harmonics are not quite as harmonically placed as on the Bach, there are more upper overtone peaks, suggesting that this instrument will ring more easily in the higher register. This supports common trombone performance practice – larger-bore instruments play more easily in the middle and lower ranges than smaller-bore instruments.

Another useful perspective from this data can be obtained by creating a graph showing the input impedance on the same graph as the radiation transfer function (which relates the

[16] Braden, et al., p. 2406

pressure radiating from the instrument). (Figure 10) In this example, the same two trombones are compared – the Bach 50B and the Conn 32H. Input impedance measurements are plotted in the top graph, while the radiated pressure – shown as a radiated sound transfer function – is in the lower graph.

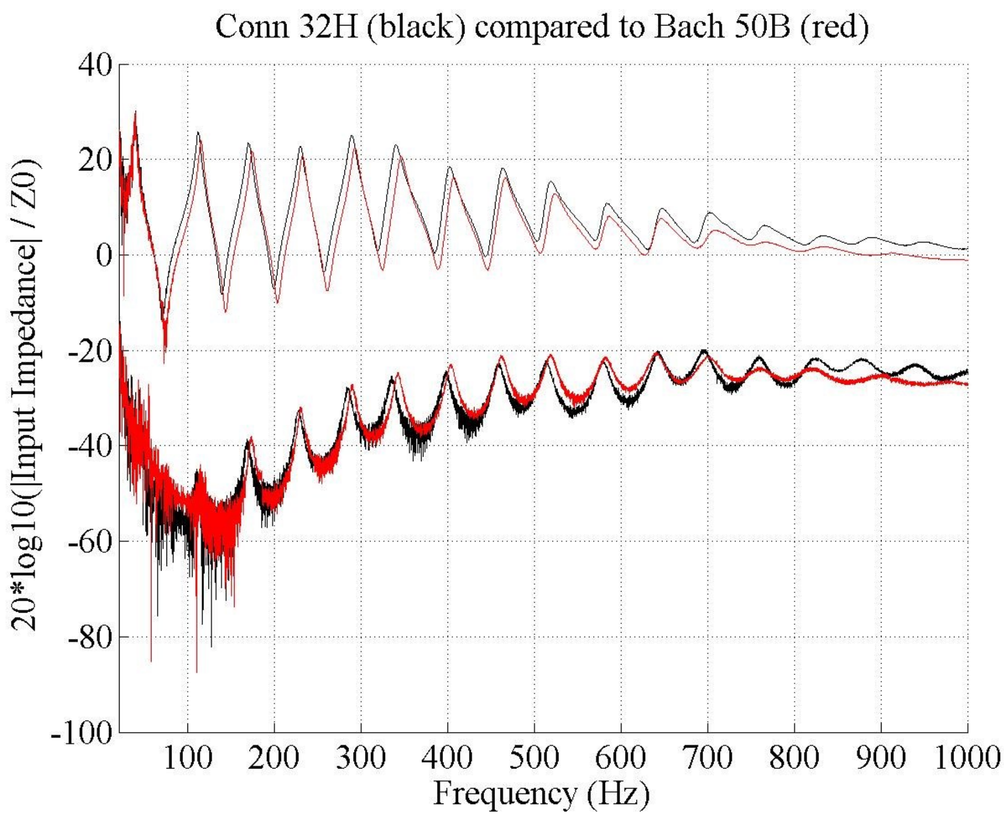

Figure 10 - The input impedance and radiation transfer function of the Conn 32H (black) and Bach 50B (red)

In this graph, the lower line represents the sound transfer *out* of the bell during the input impedance testing; in short, while input impedance shows a lot about how a horn feels from the perspective of the player, the radiated sound measurement indicates more about the resultant sound to the listener. The resonances of the radiated sound line up closely with the impedance peak frequencies, while the amplitude of each peak indicates the relative strength of that frequency component that radiates compared with that forced into the instrument at its input end.

For example, there is significantly more low-frequency energy inside the instrument compared to high-frequency energy, the latter of which more readily propagates out through the bell. Note, however, that the radiated transfer function should not be interpreted as representative of the spectral content of the sound that radiates from the instrument.

2.3 Limitations

This testing method is not without shortcomings. First, the testing system vibrates the instrument at a relatively low amplitude (compared to the pressure levels under playing conditions), and therefore may not be perfectly analogous to "real-world" trombone playing, which is often at a very high pressure levels.

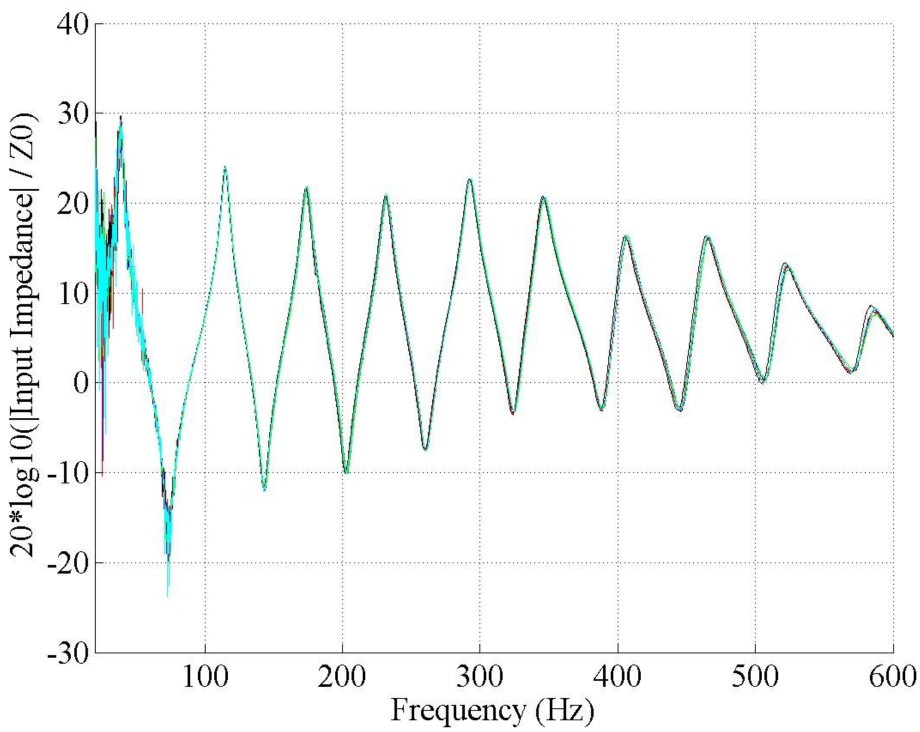

Figure 11 - Five input impedance measurements of a Greenhoe modular trombone, each using a different bell. Though all five bells are plotted here, each using a different colour line, they are similar enough to appear as only one line.

It should also be noted that the lower frequencies of the radiation transfer function suffer from low signal-to-noise levels due to the ambient sound in the measurement space; this explains the lack of similarity between the two plots in the frequency range below 200 hertz.

Also, it should be noted that bell design – by itself – generally showed little to no change in the data. For example, Figure 11 is a plot of just the input impedance measurements of all five of my bass trombone bells, using the same slide. There isn't much difference in the data, even though, after play-testing each bell with a recording device, I have found that there is certainly a difference in both sound and feel between them.

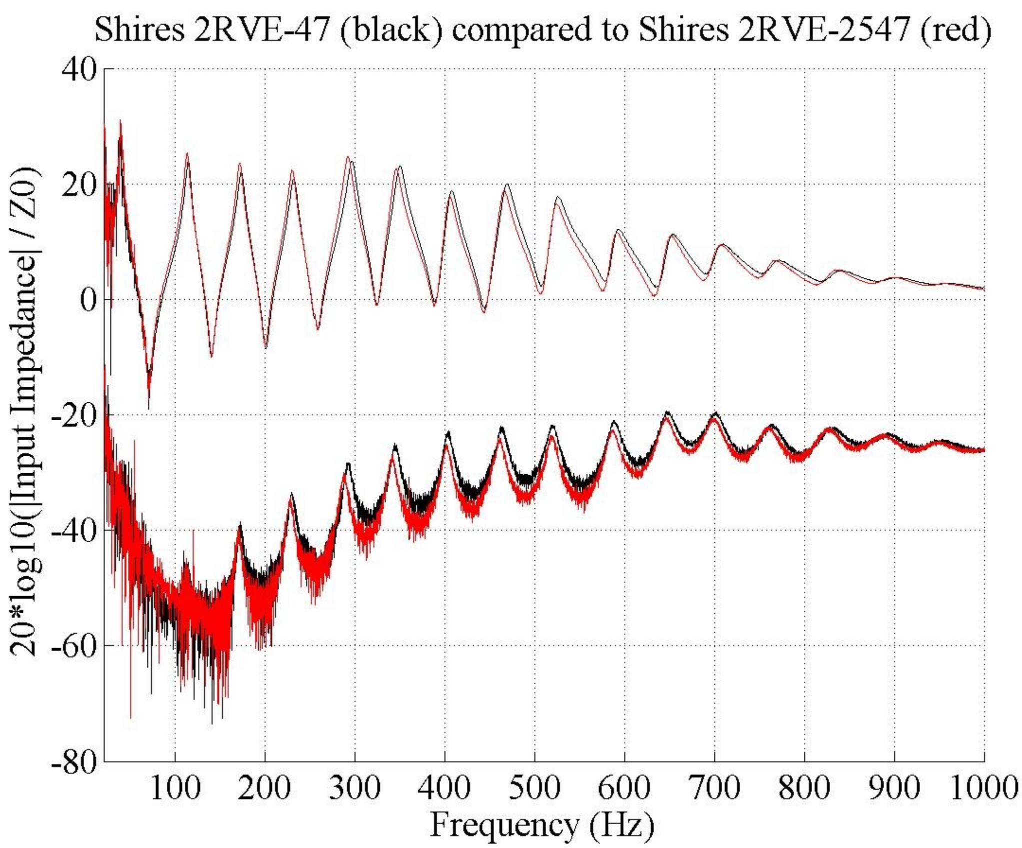

Figure 12 - Input impedance and radiation transfer function of the same Shires bell section (2RVE), with the large-bore slide in black and the medium-bore slide in red.

Different slide bores, however, affect these measurements more significantly. In Figure 12, the measurements both are from the Shires 2RVE bell section; only the size of the slide bore was different. Unlike Figure 11, where changing bells alone produces virtually no difference in these measurements, changing slide bore size alters both the amplitude and the frequency, particularly in peaks 5-10.

Simply put, the input impedance measurement system measures the natural resonances of the instrument, and bell design, by itself, does not affect the resonance frequencies to the same extent that the bore size and profile do. As such, I found it to be a useful data point mostly in relation to bore size. Nevertheless, these objective measurements are somewhat useful in predicting which modular combinations were most likely to be suitable replacements for the fixed-trombone choices I had made based on the historical data and my own listening.

Chapter 3 – Modular Trombones as Replacements for Fixed Trombones

3.1 Introduction

In this chapter, I examine two orchestral works that are commonly performed using very different trombone equipment – the Mozart *Requiem* and the Eighth Symphony of Anton Bruckner. For each work, I first examine the fixed trombone designs that are commonly used in modern orchestras (and the historical reasons for their use). I then focus on three different combinations of modular tenor and bass trombones of varied similarity to the appropriate fixed instruments, for the purpose of determining which modular equipment might make a suitable replacement.

Included with this document is a DVD containing demonstrations of each orchestral excerpt as played by a complete low brass section, first on traditional, fixed trombones, followed by each of the three modular trombone combinations described herein. All video excerpts are taken from my doctoral lecture-recital, *Interchangeable Parts: A Comparison Of Common Trombone Designs With Their Modular Counterparts*, given at McGill University on 18 September 2014.

In each case, I made my equipment choices using a combination of historical trombone data, common modern orchestral performance practice and laboratory data. I then play-tested each of my equipment choices in a low-brass section to observe the real-world results.

3.2 Case Study – Orchestral Excerpt, "Mozart: Kyrie from the Requiem"

As described in Chapter 1, the Mozart *Requiem* was written with the very small trombones of late-18th century Vienna in mind.

As previously mentioned, common practice in modern orchestras for these types of works is for the first trombonist to play alto, the second trombonist to play a medium-bore instrument, with the bass trombonist playing his/her part on a large-bore tenor trombone, rather than an actual bass trombone. (Figure 13)

For the purposes of both testing and demonstration, I selected two fixed trombones that met this criteria: a medium-bore Conn 32H for the second part, and a large-bore tenor trombone (a Conn 88H) to play the bass trombone part on. In all cases, the first trombone part was played on alto trombone, though due to its completely different length and fundamental pitch, the alto trombone was not included in laboratory testing.

Figure 13 - The Trombones of the Royal Concertgebouw Orchestra, touting their "scaled down" equipment via social media[17]

[17] https://www.facebook.com/trombonesrco/photos/a.586881868030266.1073741827.117668144951643/671257506259368/?type=1

Once I had selected traditional trombones for each part, I then proceeded to compare them to a number of different combinations of modular equipment. To determine which modular tenor was closest – in both sound quality and feel to the performer – to a medium-bore tenor trombone, I generated a comparison graph, showing the input impedance of the Conn 32H, and two different Shires trombone setups – once using the medium-bore slide, and again, using the large-bore slide. (Figure 14)

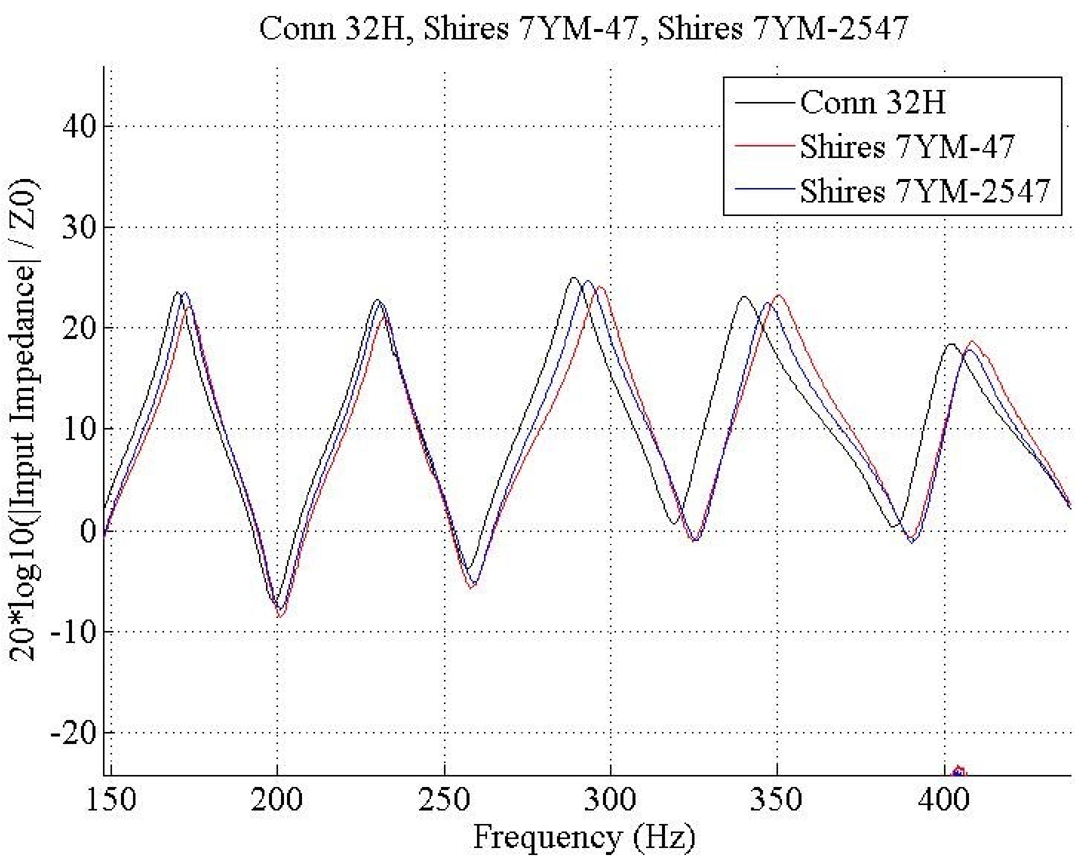

Figure 14 - A comparison graph showing input impedance peaks for the medium and large-bore tenor trombones

In this graph, the larger-bore slide is indicated in red, while the smaller slide is plotted in blue. The 32H is in black. Note that, while the peak impedance frequencies are all quite similar, the larger-bore slide has a lower amplitude and a slightly higher frequency for most overtones, indicating that the smaller slide will likely produce results more similar to the 32H than the larger-bore slide.

When selecting a modular trombone for the bass trombone part, I first compared the input impedance measurements of the Conn 88H tenor trombone to a number of different configurations of the Greenhoe modular bass trombone. First, I examined the effect of slide bore, by comparing the input impedance and radiation transfer function resonances of the 88H with those of the Greenhoe bass trombone with a bell of the same design as the Conn (the Shires 2RGLW.)

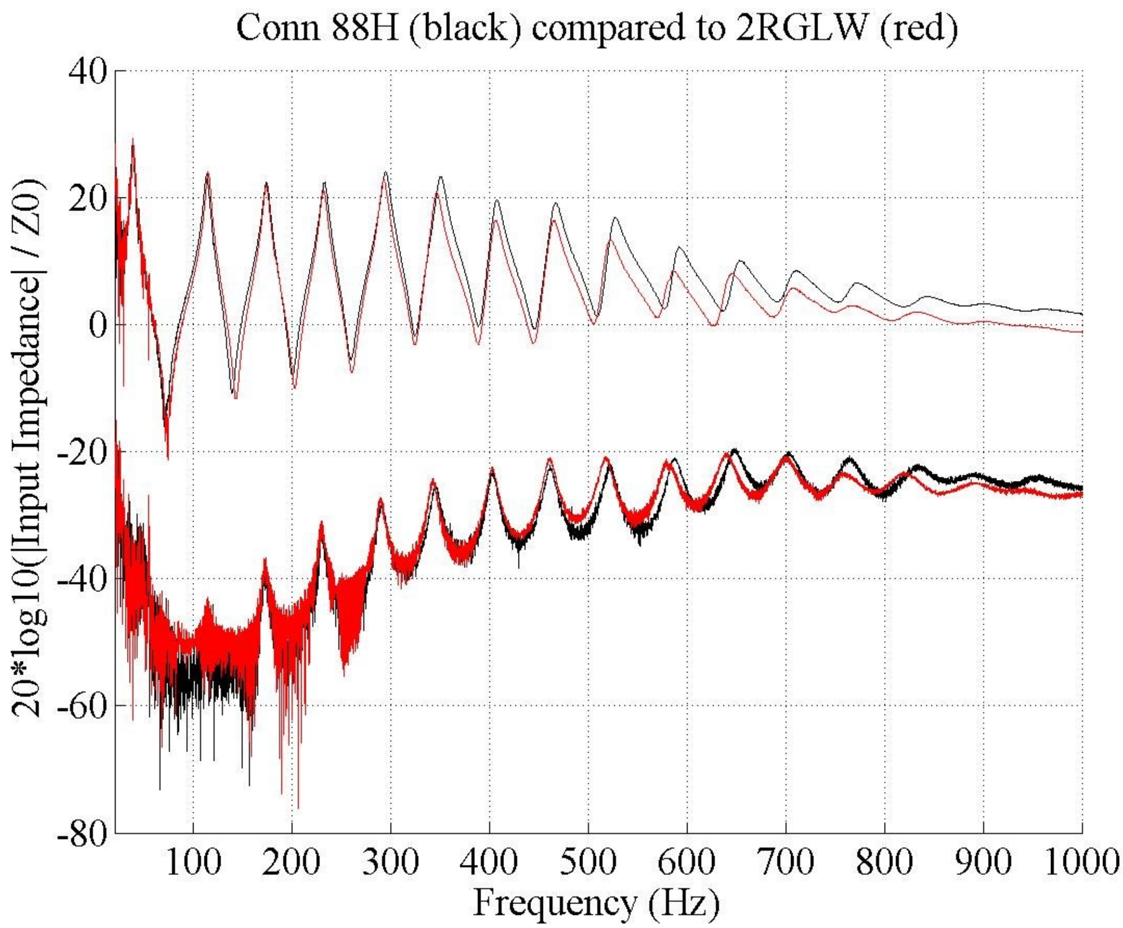

Figure 15 - Input impedance and radiation transfer function comparisons of the Conn 88H and the Greenhoe using the 2RGLW bell

In this case, despite the similar bell choice, there is a very significant difference between these instruments in the upper harmonics. The smaller-bore Conn 88H has significantly stronger harmonics in the middle and higher frequencies than the Greenhoe bass trombone. (Figure 15)

Next, the Greenhoe bass trombone with the smaller .547 inch slide was tested; this happens to be the same slide bore as the Conn 88H. The results show that the smaller slide bore brings the modular bass trombone setup much closer to the Conn 88H setup than the standard bass trombone slide. (Figure 16)

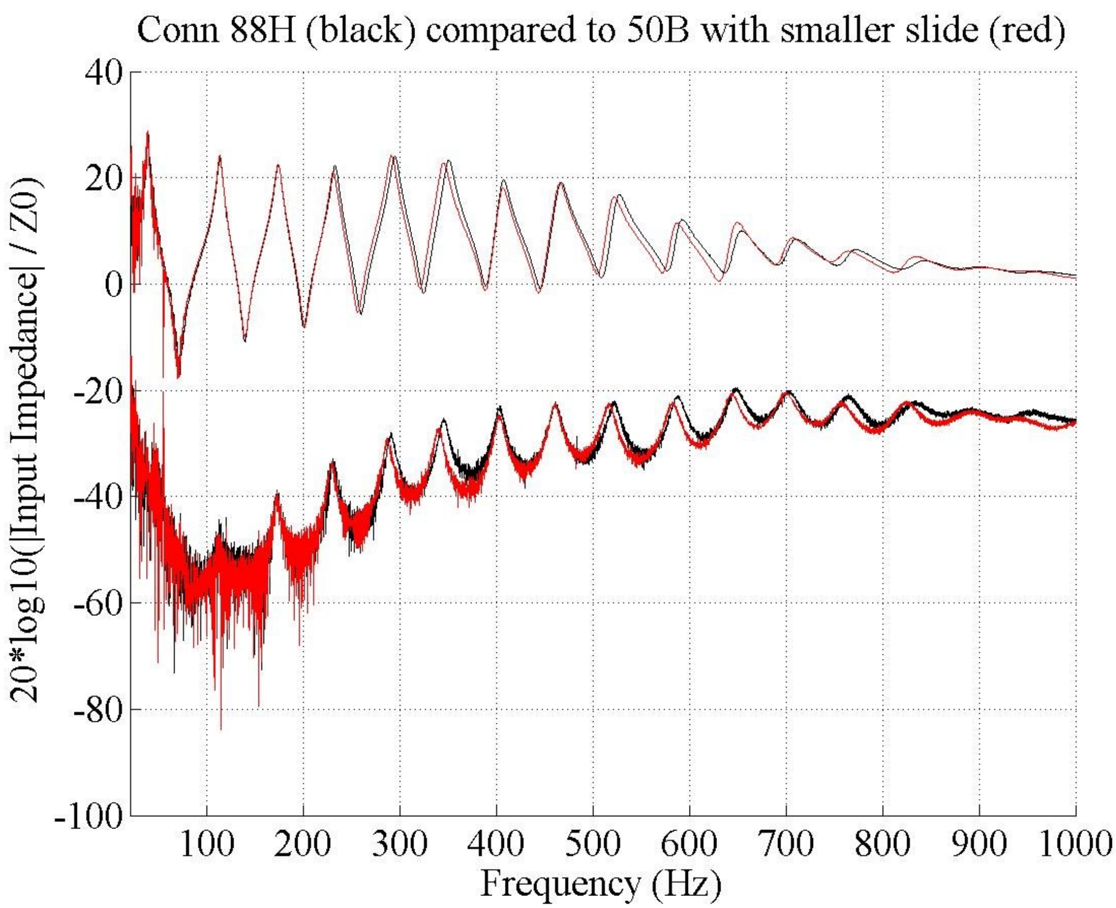

Figure 16 - Input impedance and radiation transfer function comparisons of the Conn 88H and the Greenhoe using the smaller slide

This graph indicates that virtually every single resonance between the two instruments is significantly closer together in frequency, amplitude, and damping when compared to Figure 15. Accordingly, one would expect that the Greenhoe bass trombone using the smaller-bore bass trombone slide would sound and feel more like the Conn 88H than the Greenhoe with the larger slide bore.

For the purposes of demonstration, I performed this excerpt during my lecture-recital in a low-brass section using four different sets of trombones; it can be viewed on the included DVD, or at the included YouTube link.[18] The video on this recording is from a Sony hi-definition (1080p) camcorder located in the back of the audience, and two audio sources were recorded – the first from the camcorder, the second from microphones near the stage.

The audio source used in the video is from the camcorder, chosen primarily because it is a good representation of what an audience member might experience. The microphone recording, while clearer (and thus useful for detecting small articulation and intonation deficiencies), failed to capture any reverberation from the concert hall. This resulted in a recording that sounded dull, with very little sense of blend or balance between the different performers.

The first demonstration showed that, on small modern trombones, this particular excerpt has a bright, top-heavy sound; the alto trombone is very prominent. All members of the section found intonation and balance reasonably easy to manage.

The second demonstration was intended to demonstrate modular equipment that *isn't* appropriate – in this case, the second trombone played a large-bore Shires tenor, while I played the Greenhoe with the 2YHW bell and large slide. The results were quite poor; one can hear the bottom two trombones easily overpowering the alto. In the struggle to be heard in such a texture, the alto player "cracks" a few notes as a result of overblowing.

The third demonstration was also played on large-bore tenor and bass trombones, though using lighter weight bells made of gold brass, as opposed to yellow brass. Though the sound is a

[18] https://www.youtube.com/watch?v=3v20V8N_084. The performance on fixed trombones begins at time marker 16:30, with the modular trombone performances at 18:10, 20:16, and 21:40.

bit more subdued in the lower parts, it is still very difficult to make out the alto trombone in the texture, though the sound quality does resemble that of the smaller trombones a bit.

Finally, for the fourth demonstration, both the second and the third trombonist switched to smaller slides, resulting in a sound that, as suggested by the laboratory readings, was much more similar to the original fixed trombone choices. Balance was also notably improved, and the alto trombone sound is prominent again. It should also be noted that the two performances that contained the least amount of "cracked" notes were the first and the fourth, suggesting that these smaller-bore instruments might feel easier to play to the performer.

3.3 Case Study – Orchestral Excerpt, "Bruckner: Symphony #8, Movement 4"

In the case of Bruckner's eighth symphony, the desired sound and feel are a polar opposite from those of the *Requiem*.[19] The opening of the fourth movement (Figure 17) is a perfect example; it is comprised of long, fortissimo block chords in the trombones and tuba that must be perfectly in tune and absolutely steady, with no shake or wobble in the sound. The orchestration further exacerbates these requirements, as a Bruckner orchestra is massive, making projection just as important as intonation and stability. Still, the sound must be warm and in control, without breaking up or sounding too harsh.

Figure 17 - Low Brass Parts, Anton Bruckner, Symphony #8, Mvt. 4

[19] Wick, p.79-80

Historically, we know that the trombones of Bruckner's time were more similar in size and design to the trombones being played today. The first two parts would have been played on tenor trombones with a bore size ranging from about .524 inches (like today's medium-bore trombones) to .547 inches (like modern large-bore tenors), while bass trombones were already using the .562 inch bore size still standard today.[20] Therefore, common practice today is to use standard, large-bore orchestral trombones when performing this symphony.

The fixed horn section selected for testing and demonstration in this case consisted of the first and second trombone parts being played on Bach 42B large-bore (.547 inch) tenor trombones, and the third part on a Bach 50B (.562 inch bore) bass trombone. A recording of this demonstration can be viewed on the included video.[21]

Selecting modular horns to match these selections is a simpler task than with the Mozart, since the default setups on both the Shires and Greenhoe trombones are of the same bore size, bell size, and bell material as the fixed Bach trombones. Still, I sought to determine if the impedance readings would indicate this, or perhaps point toward a less intuitive result.

First, the two large-bore modular tenors, the 7YM and the 2RVE (Figure 18), were compared to determine if the bell of the modular trombone selected resulted in readings that were closer to those of the fixed Bach 42B. While there are some small differences between the impedance peaks of each of these instruments, they are largely similar in amplitude, frequency, and width. The lower resonances are almost completely identical, and the higher ones are only slightly higher in frequency on the Shires trombones than on the Bach. Neither modular bell choice appears to be closer to the 42B bell than the other.

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[20] Guion, p. 64-66; Myers, p.49

[21] https://www.youtube.com/watch?v=3v20V8N_084, at position 33:20

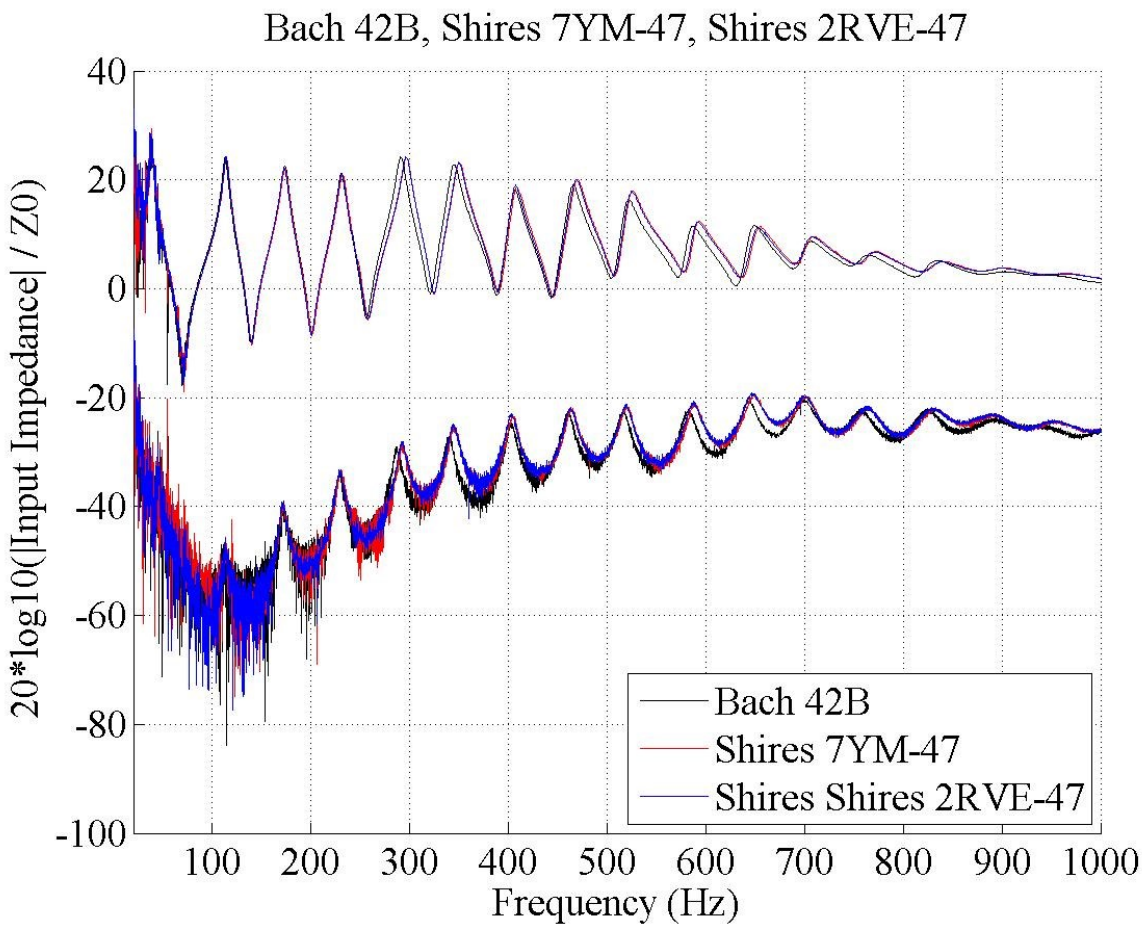

Figure 18 - Input impedance and radiation transfer function comparisons of the Bach 42B with the Shires 7YM and 2RVE bells. All three are using large-bore slides

Next, to determine the effect of smaller slide bore, measurements of the 42B were compared to two different readings using the yellow-brass modular bell – the first with the large-bore .547 inch slide, and the second with the .525 inch medium-bore slide. The results here are mixed; the two closest readings – particularly at the second, fourth, and fifth peaks shown on the graph (Figure 19) – are between the *large-bore* 42B and the *medium-bore* Shires, though both Shires trombones are more similar to each other than to the Bach in the upper frequencies. As such, this data only supports the conclusion that neither Shires trombone matches exactly to the Bach 42B, though both are close enough to be adequate replacements.

During play testing (as can be heard in the demonstration of the Bruckner excerpt on smaller-bore equipment[22]) the sound on this excerpt was found to be generally too bright and harsh at louder volumes on medium-bore tenor trombones, compared to large-bore trombones.

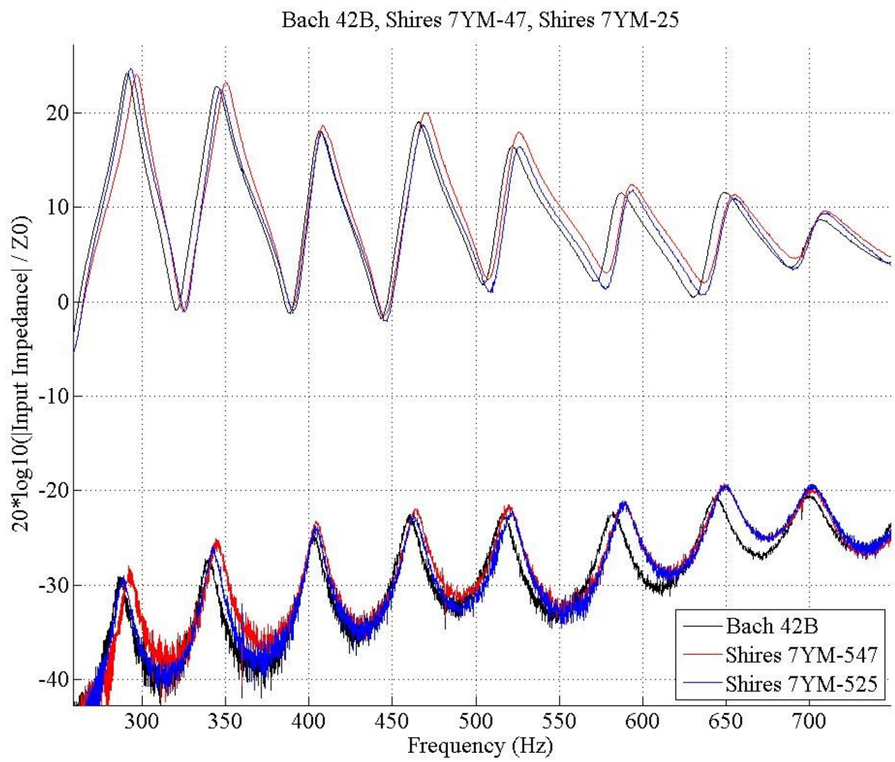

Figure 19 - Input impedance and radiation transfer function comparisons of the Bach 42B with the Shires large-bore and medium-bore slides.

In the case of the bass trombone, the results were somewhat more in line with the results of play-testing. Previously, input impedance tests showed no difference between different bass trombone bells when the same slide bore is used (Figure 11), so for these tests, only different slide bores will be considered.

The standard Bach 50B bass trombone has impedance peaks closer in frequency and amplitude to those of the Greenhoe modular bass trombone with the standard slide, rather than

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[22] https://www.youtube.com/watch?v=3v20V8N_084 at position 37:20.

the smaller slide. (Figure 20) This suggests that the standard Greenhoe bass trombone slide would sound and feel closer to the standard 50B slide.

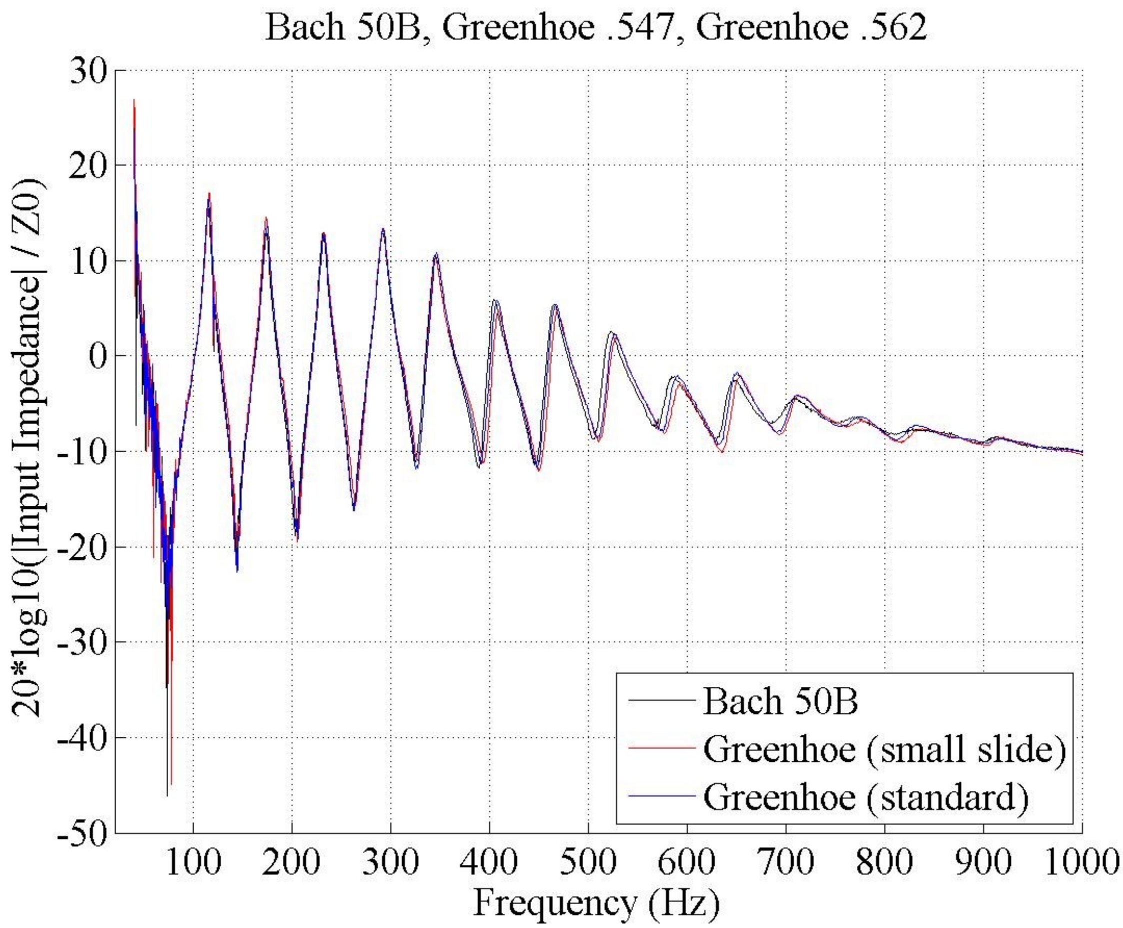

Figure 20 - Input impedance and radiation transfer function comparisons of the Bach 50B with the two different Greenhoe slides. The "small slide" refers to the .547 inch bore bass trombone slide, while the "standard" refers to the .562 inch large-bore bass trombone slide.

During the first demonstration[23] the excerpt is played on the fixed-design, large-bore trombones. For the second demonstration[24] we played similar modular trombones to those that had worked well on the Mozart - the first trombonist used a medium-bore tenor, and the second player used a large-bore modular tenor trombone. I used the smaller bass trombone slide for the third part. All three modular trombones were set up with gold-brass, unsoldered-rim bells (the

[23] https://www.youtube.com/watch?v=3v20V8N_084, at position 33:20
[24] https://www.youtube.com/watch?v=3v20V8N_084 at position 37:20.

2RVE and 2RGLW), which are intended to emulate the bells of Conn trombones, rather than Bach.

During this performance, it becomes quite clear that the wrong set of modern, modular trombones can be a clear step backward in tone quality, intonation, blend, and balance. The sound is bright and shrill, “breaking” at the louder dynamics on the smaller instruments, often accompanied by faulty intonation and an unstable sound. Again, this contradicts the information gathered from the input impedance tests (Figure 18) in the tenor trombones.

For the third demonstration,[25] all three trombonists switched to large-bore setups, though they continued to use gold-brass, unsoldered bells. While the sound, intonation, and blends were all noticeably improved, it was still noticeably less blended of a sound, with more resulting middle and higher overtones than the fixed Bach trombones of the first demonstration.

The final demonstration[26] employed the Shires 7YM (Bach 42-like) bells on both tenor trombones. The bass trombone part is played on the unique heavyweight 2YHW bell, which is described by the manufacturer as being well-suited for loud orchestral playing. During play-testing, it was determined that these modular combinations sounded similar to their Bach counterparts, and that the heavyweight bass trombone bell actually contributed to a superior sound and feel when compared to the Bach 50B.

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[25] Ibid, position 39:45.
[26] Ibid, position 42:04.

Chapter 4 – Modular Trombones as a Means to Tailor the Sound for Solo Literature

4.1 Introduction

Unlike many other orchestral instruments, there is very little solo literature for the trombone, and far less amongst literature written prior to the mid-20th century. As such, we generally have to rely upon transcriptions of works written for strings, woodwinds, and voice if we wish to play quality music from the baroque, classical, and romantic periods.

In contrast to the orchestral literature, which has very specific sonic requirements based on historical performance practice and ensemble needs, solo literature allows the performer the freedom to tailor their sound to their own artistic preferences. Generally speaking, when I am selecting the equipment for each piece, I'm looking for the instrument that feels the most comfortable to play, while still sounding appropriate for the work. My intended sound is determined from a combination of historical practices and practical considerations (such as accompaniment style, balance, range, etc.), as well as my personal preferences.

Determining what feels and sounds good for solo works involves mostly self-observation. In the practice studio, I perform a segment of the work I am preparing, with the video and audio recorder running. I generally try every possibility available, making detailed notes on how I perceive each setup to feel and sound while playing - does it articulate easily? Does it seem to require more air to maintain tone? Is it a direct sound that's more difficult to hear from the performer's point of view, or is it a more "diffuse" sound that can be heard more easily from behind the bell?

All of these notes are then compared to the audio and video, for the purpose of determining how different each setup sounds on the recording from my perception while playing. The video portion is carefully examined to determine if certain setups are requiring different physical maneuvers to produce the sound, particularly to determine if those maneuvers are full of tension or otherwise physically inefficient.

In terms of relating these feelings to objective data, I found that input impedance was, in certain specific cases, a good way to predict which setups would more closely match the sound and feeling I was after. For instance, with the Bozza New Orleans, I want to sound like a jazz bass trombone. Therefore, I would start my experimentation in the practice room with the instrument that has the most similar input impedance measurements to the jazz bass trombone that I have access to – in this particular case, the King Duo Gravis.

Once I have all of this information gathered, I use it assemble the modular trombone that I believe sounds and feels the best for the work at hand. In this Chapter, I present four different solo works, each with very different sonic requirements and technical challenges, and each performed on a different configuration.

4.2 Case Study – G.P. Telemann, *Sonata in f minor*

This Baroque solo piece, as originally conceived, would have been performed on an early version of the bassoon, which has a light, airy tone capable of clean, quick articulation and long phrases. Of course, imitating this particular tone on a bass trombone is a largely impossible task, but, as with any transcription, perfect authenticity is not the concern here. What I'm looking for is an instrument with a small, clear, direct sound – like an early bassoon – that is also easy to play lightly.

I found, after comparing both audio and video to my observations of feeling and response, that the bells with soldered rims met my requirements for clarity and quick response more efficiently than the unsoldered rim bells. I also determined that the transparent quality I sought was most easily achieved using yellow brass, rather than gold brass. It was also apparent that using the heavyweight bell involved more tension while playing, as though it required more physical exertion to produce the attack and sustain portions of each note.

The input impedance data graph, however, does not seem to support these findings, as there is very little difference between the impedance measurements of each bell. Here we have my standard Bach 50B bell compared to the two unsoldered-rim bells – one made from yellow brass, and the other made from gold brass. While there are some differences between the radiated transfer function measurements, the results at low frequencies have very poor signal-to-noise characteristics and cannot be used to make any conclusions.

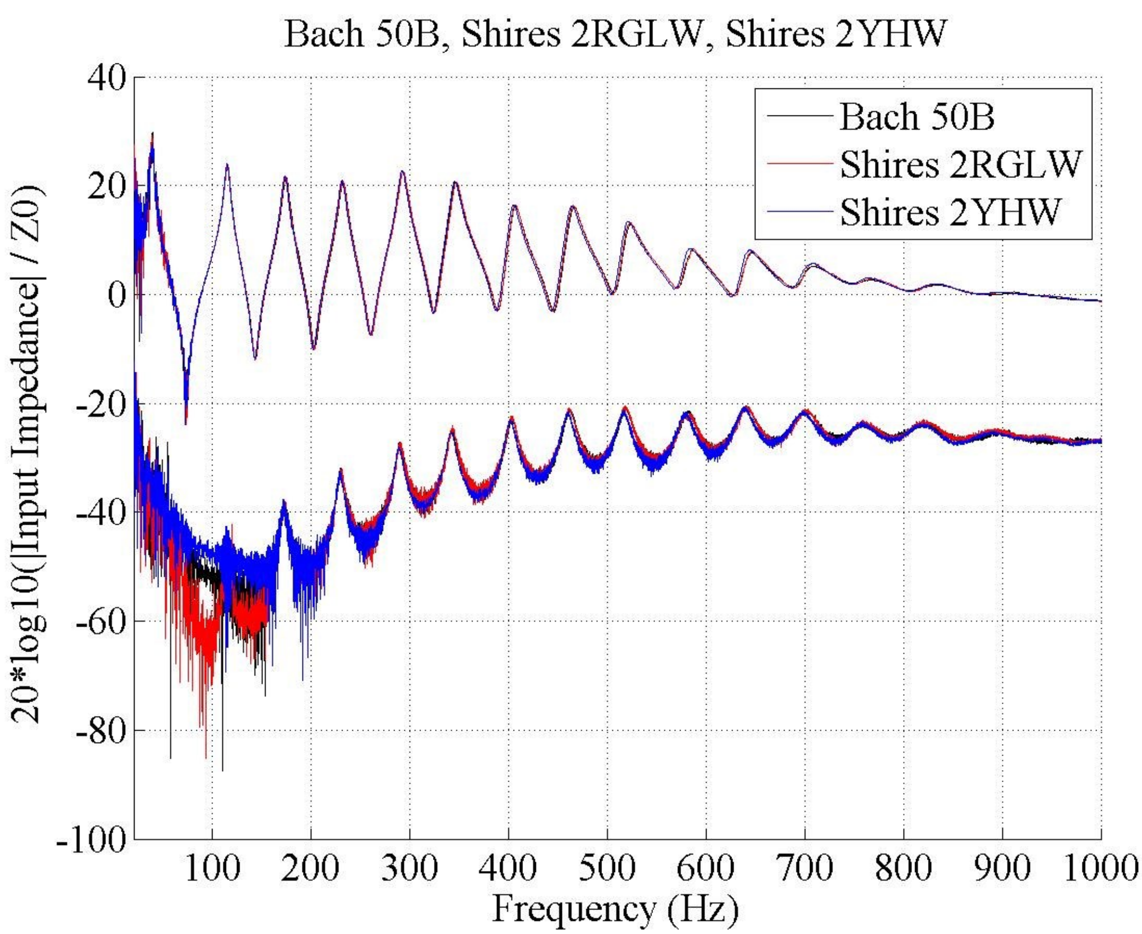

Figure 21 - Input impedance/radiation transfer function comparison of the Greenhoe using the 50B, 2RGLW, and 2YHW bells

My own recording and observation has led me to prefer the standard 50B bell on my modular setup when performing this sonata. I find that the soldered, lightweight, yellow-brass bell allows me to articulate more sharply without sounding "thuddy" or "woofy," particularly in the lower dynamics that this work demands.

A demonstration of this work on this instrument can be found on the included video.[27]

4.3 Case Study – Robert Schumann, *Dictherliebe*

One of the oldest traditions among trombonists is the relation of the sound of the trombone to the sound of the human voice. The teaching methods of Johannes Rochut, Emory Remington, Arnold Jacobs, and Charles Vernon all revolve around the concept of trombonist as singer in regards to air support and phrasing. It is from this tradition that I have been inspired to myself transcribe four songs from Schumann's song cycle, *Dichterliebe*, for bass trombone and piano.

When selecting equipment for this piece, I wanted a sound quite different than what I achieved with the Telemann. This staple of the Romantic lieder requires a sound that is thick and resonant, with easy connections between notes. While articulation does need to be clean, I am not looking for the same "pointed" quality that the Telemann requires.

Again, when comparing bells using input impedance, there isn't a lot in the data that suggests a difference between bells that fulfills these requirements. Using my 50B as a baseline, I was looking for evidence that one bell sounded and felt heavier and more covered than the others, however, nothing in any of these graphs suggested this. (Figure 22)

[27] https://www.youtube.com/watch?v=3v20V8N_084 at position 51:15

Therefore, I was left to recording and play-testing. My own process of recording myself and documenting my comfort when performing this work showed that using the heavy, unsoldered rim bell resulted in a dense sound with a more covered articulation. I also found that the heavy bell feels less responsive, which actually encourages me to use a thicker and more connected airstream. As such, I find the heavy weight, unsoldered bead 2YHW bell to be a good choice for Schumann lieder. A performance on this instrument can be viewed on the included video.[28]

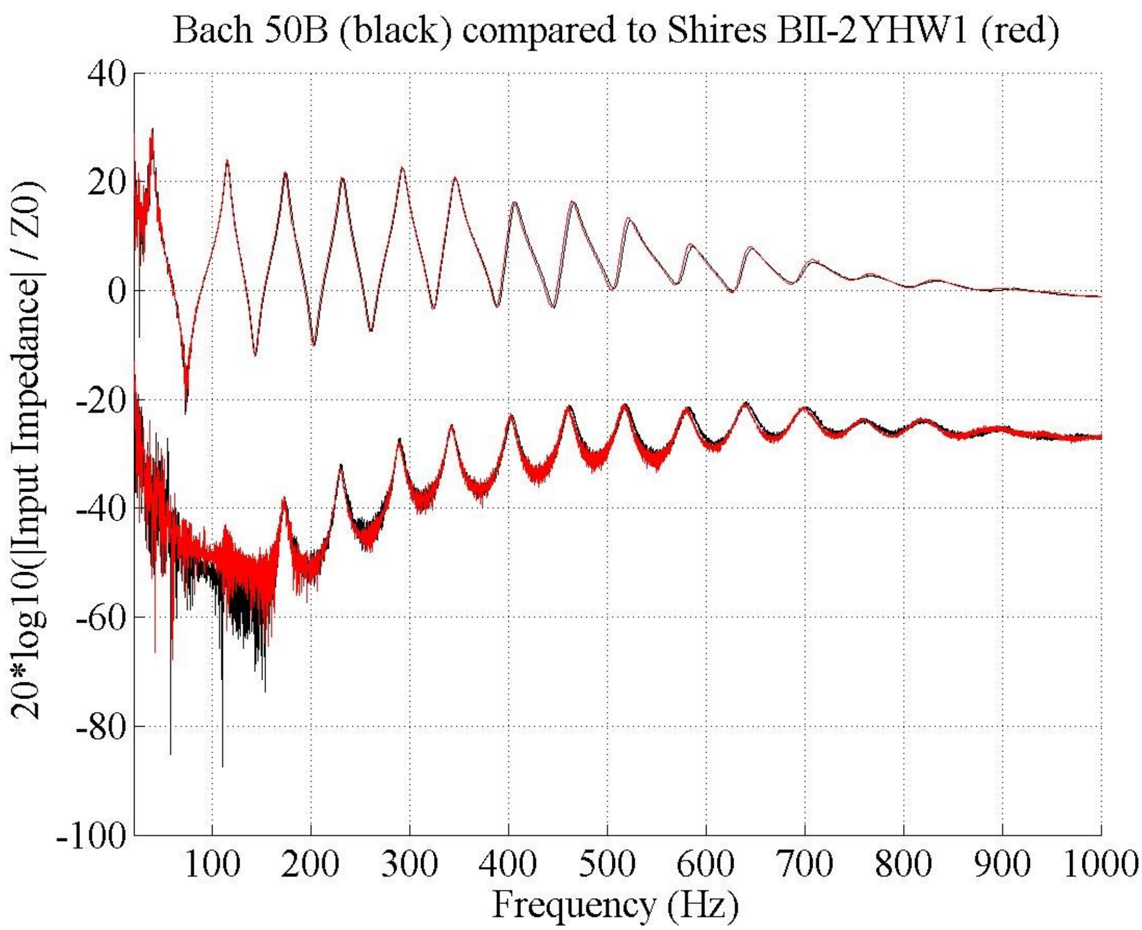

Figure 22 - Input impedances/radiation transfer functions of the Greenhoe bass trombone, using the 50B the 2HYW bells

[28] https://www.youtube.com/watch?v=3v20V8N_084 at position 58:30.

4.4 Case Study – Robert Spillman, *Concerto for Bass Trombone*

The bass trombone concerto of Robert Spillman is one of the earliest pieces of solo literature written for the bass trombone, and as such, has become a staple in our repertoire. This work alternates between fast, loud, angular passages (Figure 23) and soft, long, and lyrical phrases. It also utilizes a much wider range than the Telemann or Schumann, descending as low as the pedal E in both slow and fast sequences. Therefore, I am looking for a setup that is easier to play in the lowest tessitura, yet still capable of the cleanest articulation available.

Figure 23 - Opening of Robert Spillman's Concerto for Bass Trombone. The quick 16th notes require very clean articulations to be perceptible to an audience.

In the practice room, I found that the larger bell, the 50BL, seemed to work better than the others, particularly in the pedal register. The input impedance data does, in this case, offer a small explanation for why this might be (Figure 24); on this graph comparing the 50B, 50BG, and 50BL, there is little to no difference in the lower resonances, while the damping of the higher resonances is higher, and the amplitude of these resonances is lower. In this case, it could be inferred that the larger bell geometry is resulting in softer, less resonant higher overtones; this could help explain the darker, less edgy tone this bell provides.

As the demonstration video[29] shows, the larger bell allows for a rounder, more diffuse tone, with a low and pedal range that is significantly easier than on the smaller bells. Like the 50B, it maintains a soldered rim bead, giving me precisely what I want for this work – a rich, complex sound, with easy articulation and a vibrant low tessitura.

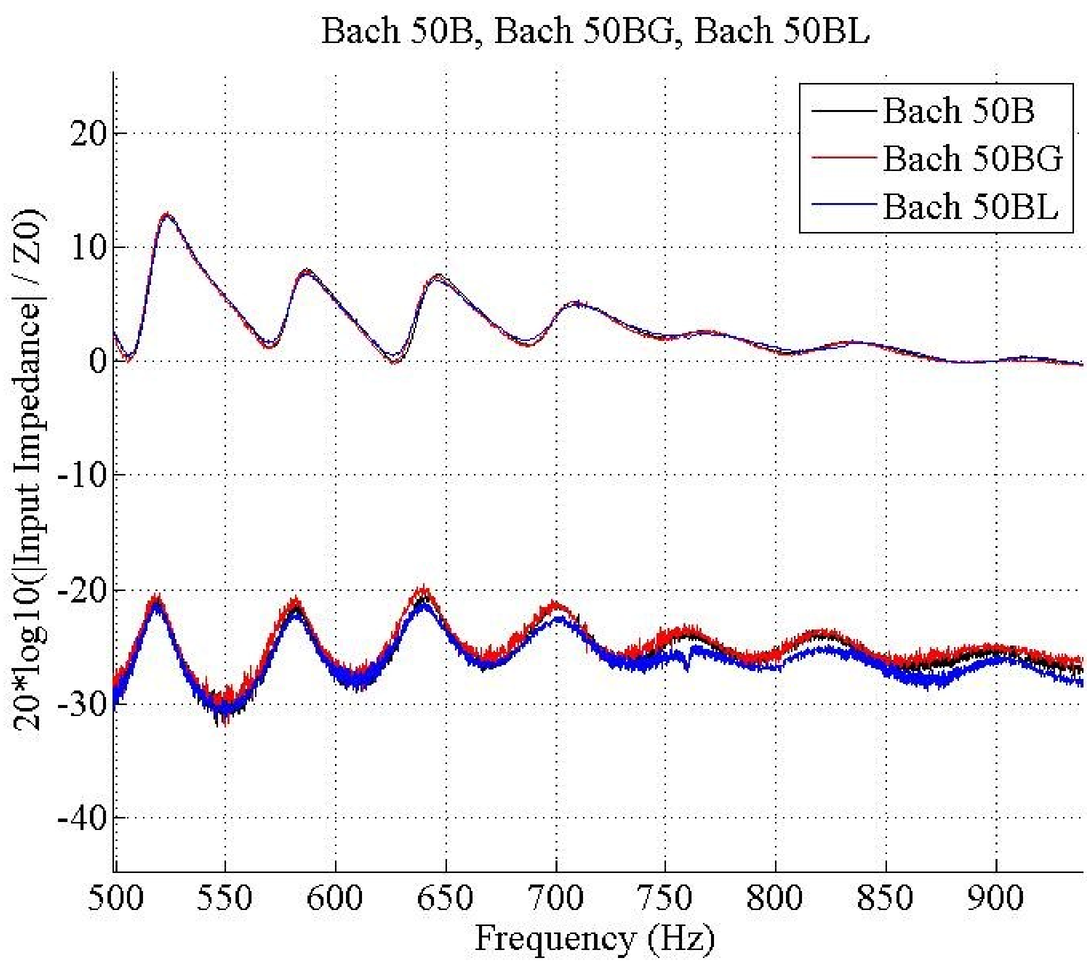

Figure 24 - Input impedances/radiation transfer functions of the Greenhoe bass trombone, using the 50B, 50BG, and 50BL bells

[29] https://www.youtube.com/watch?v=3v20V8N_084 at position 1:07:35.

The larger bell was not without some serious drawbacks, however. First, during rehearsals, my accompanist reported that hearing my part was much more difficult when played on the 50BL bell than the others. Also, during a number of moments in this performance I experienced significant difficulties articulating in the upper tessitura; broken articulations are particularly noticeable in this range at the 1:11:43 mark. (Figure 25) Still, the ease of articulation and sustain in the pedal register (particularly the pedal F in the cadenza, shown in Figure 26) outweigh these issues for me.

Figure 25 - Rapid range shifts in Spillman Concerto. The highlighted passage can be harder to articulate on a larger bell.

Figure 26 - Extreme low register playing required by the cadenza of the Spillman.

4.5 Case Study – Eugene Bozza, *New Orleans*

Eugene Bozza's *New Orleans* is a work thoroughly steeped in jazz. As such, when preparing this work, I sought a tone as close to the modern American jazz bass trombone as I could find. In this case, I decided once again to go with a modular instrument similar to that of a fixed trombone – in this case, the King Duo Gravis.

The technical demands of this work are extreme – the range is from pedal F all the way up to high B-flat, a three-and-a-half octave range. The articulation required runs the full gamut from quick, secco 16th notes peppered with random accents, to sloppy, glissando-laden lyrical phrases. (Figure 27) The dynamic demands are also quite varied; I am required to play both as softly and as loudly as I ever would in a solo context.

Figure 27 - Cadenza section from Bozza's New Orleans. Note the wide range of the measure before Rehearsal 3

It should be said that I have no exact setup that is built in the same way as the Duo Gravis; therefore, the input impedance and radiation transfer function data becomes more useful. Figure 28 is a comparison of the impedance measurements of an actual Duo Gravis with those of each of my bells. In this case, the Shires 2RGLW bell comes slightly closer, both in actual placements of resonance frequencies as well as amplitude.

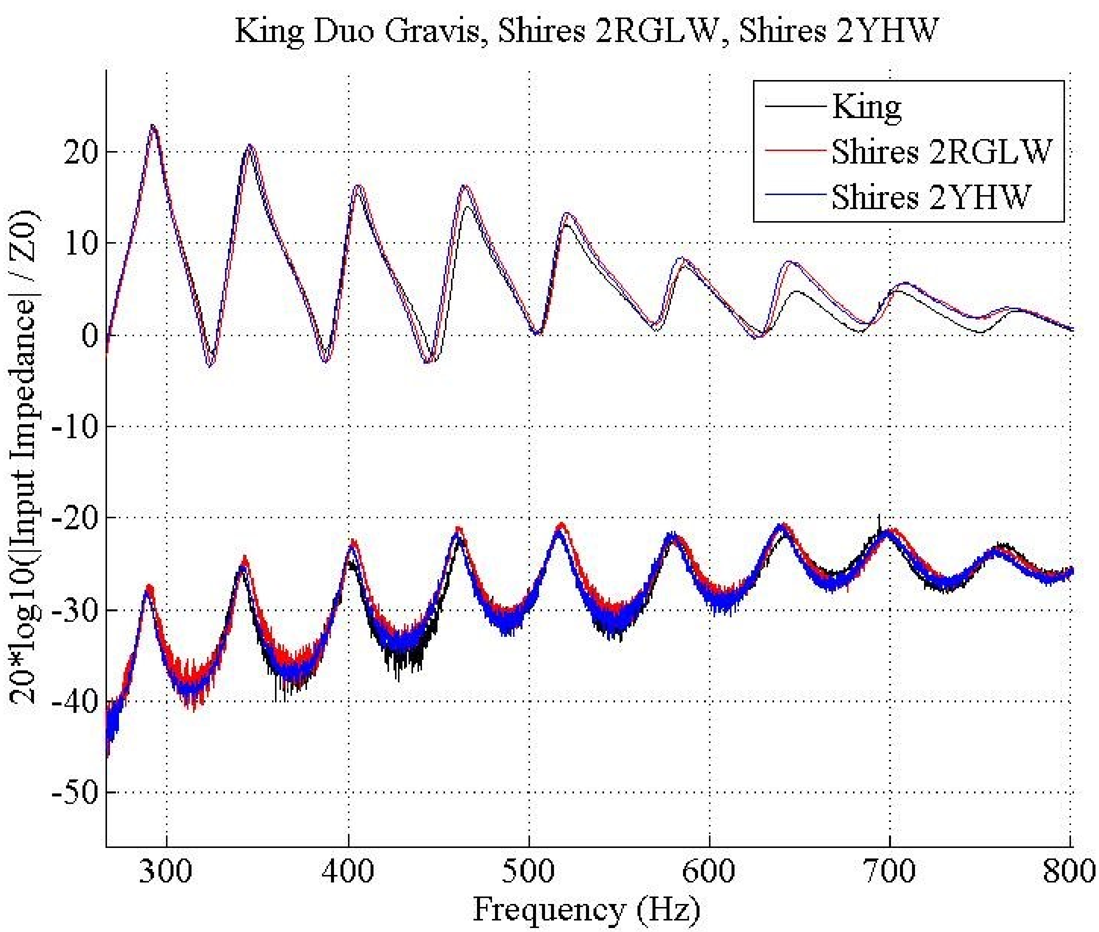

Figure 28 - Input impedances/radiation transfer functions of the Duo Gravis, compared to the Greenhoe using 2RGLW and 2YHW bells

Indeed, my findings in the practice studio match quite closely to this finding. This thin-wall, rose brass bell with an unsoldered rim bead allows me both the fuzzy soft tones of a trombone ballad as well as the out-of-control, over-the-top loud and high playing typical of a commercial or big-band player that this work calls for.

One moment in particular was significantly easier to play (both as perceived by me, as well as indicated by the audio and video) on the King and the 2RGLW when compared to the 2YHW. This passage begins with a quick dectuplet scale passage leading up to a high A, followed by a quick descent down through an augmented triad, landing loudly on pedal F. (Figure 27) Though the pedal F was louder and more stable on both the 2YHW, as well as the larger 50BL, it took a number of attempts to "hit" the high A without cracking the articulation on both bells. In contrast, the Duo Gravis and the Greenhoe using the 2RGLW bell both were consistently easy for me to play the passage on without errors from the first attempt onwards. Video recordings also revealed a much less tense physical appearance while playing these instruments, as well.

The included video includes two different demonstrations of this work; first, I performed the introduction on an actual King Duo Gravis jazz bass trombone (at time marker 1:14:25), as well as a complete performance on the modular Geenhoe bass trombone using the 2RGLW bell (time marker 1:19:08.) In these performances, one can observe the similarity between the sound of the King and the 2RGLW. It is also quite apparent that the lower registers have less body than those of the Spillman, while the upper register is significantly clearer and easier to play (resulting in fewer "broken" articulations.)

Conclusion

This study began with two goals – first to determine if modular trombones could be used to emulate a number of different types of fixed trombones through the use of different combinations of bell and slide. In the second I sought to explore ways in which a performer can use modular horns, not as merely a sound emulation tool, but also as a means of tailoring one's trombone sound to their own unique aesthetic preferences.

Through input impedance testing as well as the demonstrations offered, it is clear that some modular equipment choices are better for replacing fixed trombones than others. In particular, matching bore size to that of the desired fixed trombone design is crucial. When carefully selected, a modular trombone can work as well as, or even better than, the fixed trombones traditionally used in various orchestral roles. Poorly selected trombones, conversely, can adversely affect the result.

Second, it is also clear that different bell selection has a significant impact on the ease and sound quality of solo bass trombone playing, particularly when bell design is considered. Performers using different modular trombone equipment can use "specialty" bells (of different size, design, or weight) to more closely fit their preferences in regards to intonation, ease of articulation, and range. Works with significant jazz/commercial influences may also be better served by equipment more closely matching jazz-oriented instruments.

This research raises a number of questions which open up the possibility of further study. First, though the demonstrations and player observations clearly show differences in both the sound and feel of trombones using bells made of different materials, the objective data available here suggested there would be little to no difference between them. Given the technical limitations of the input impedance measurement system used here, further investigation and development of testing methods would perhaps be helpful in determining what physical properties are causing these differences.

Also, further study is needed to understand what makes certain instrument choices work better for some players than others. Many players, rather than using modular trombones to give themselves multiple equipment options, instead pick out one modular trombone, selected to work best for them on most literature, in the same way one would pick out a fixed trombone. It would be helpful to, perhaps, survey current orchestral and commercial professionals to determine which uses of modular trombones are more common.

Finally, given the different sonic results between the close microphones and the audience microphones during the lecture-recital recording, a study of how well different modular trombone designs work in different performance venues might also be quite useful, both for performers selecting the designs that might work best for them, but also for builders seeking to tailor their designs to different performance situations.

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