THE DUALITY OF SETTINGS: HOW THE ACOUSTICS OF DIFFERENT AUDITION ENVIRONMENTS NECESSITATE A TWO-FOLD PREPARATION OF AUDITION EXCERPTS

by

Alexander van Duuren

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As members of the Document Committee, we certify that we have read the document prepared by Alexander van Duuren, titled *The Duality of Settings: How the Acoustics of Different Audition Environments Necessitate a Two-Fold Preparation of Audition Excerpts* and recommend that it be accepted as fulfilling the document requirement for the Degree of Doctor of Musical Arts.

____ Date: 07/25/2014
Moisés Paiewonsky

____ Date: 07/25/2014
Kelly Thomas

____ Date: 07/25/2014
Edward Reid

Final approval and acceptance of this document is contingent upon the candidate's submission of the final copies of the document to the Graduate College.

I hereby certify that I have read this document prepared under my direction and recommend that it be accepted as fulfilling the document requirement.

____ Date: 07/25/2014
Document Director: Moisés Paiewonsky

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SIGNED: Alexander van Duuren

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All of my former teachers and mentors – I will neglect to write any names here for fear of inadvertently leaving out a name or two, but you know who you are.

And finally, my parents:

I was fortunate enough to have parents who chose not to blindly dictate my career path with an authoritarian plume. They never pressured me to pursue any particular interest, instead leaving my own journey open to, well, me. In fact, I was going to be a baseball player, but it turned out I was a poor baseball player. Physical limitations notwithstanding however, all paths were open to me–except for one. My father, a physician, and the son of a physician himself, told me that he would break my fingers if I tried to become a doctor. I could do anything but that. Astronaut? Fine. Rodeo clown? Why not. But doctor? Nope. This great physician and gentle man, who in this technological day and age is rather digitally challenged, threatened to render me digitally challenged myself. I doubt the suggestion would truly have come to fruition, but I took the safe route anyway and found a loophole. This doesn't count, right Dad?

DEDICATION

To my mother, Carolyn, for putting a piano in my bedroom when I was young. I wish you were still here to see this.

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ABSTRACT

It is widely known that intonation in live professional trombone auditions is one of the most critical factors for which execution is paramount. However, the musician who practices dutifully and precisely with a chromatic tuner, even to the point of technical mastery, will not be prepared sufficiently. He or she will find that in certain environments where heavy reverberation is present, the harmonies inadvertently created are not in tune, even when equal-tempered tuning is executed perfectly, due to the harmonic interactions that those reverberations create. Therefore, it is important that trombonists know how to play auditions excerpts with just intonation, a system that accounts for harmony to deliver results that are truly in tune, for use in the solo round of an audition in such an acoustically "wet" space. This document demonstrates the need for a solution in this regard, the factors involved in a practical application of these concepts in varying scenarios, and presents analyses in just intonation of ten of the most commonly requested excerpts. In addition, guidance and resources are provided for application beyond the excerpts that have been included. It is intended that the trombonist who reads this document will have a better understanding of the basics of just intonation as they apply to solo auditions, so that the quality of his or her audition is improved by leaving at least one less element, intonation, up to chance.

CHAPTER 1: INTRODUCTION

The Importance of Intonation in Auditions

A quote from Betsy Bright Morgan, Second Trumpet with the Tucson Symphony Orchestra, accurately and anecdotally describes and supports the primary purpose of this document:

> Sometimes when I would play in an echoing hall, I would sound out of tune against the preceding parts of the phrase. Any time I would play excerpts for someone under such conditions, my feedback would be something about it being out of tune. I was getting frustrated because I knew that I was working so much on my intonation but it seemed to be getting worse in situations like that…It wasn't until years later that I realized that, when playing anything alone, it almost always has to be tuned against each whole phrase.[1]

In a professional audition setting, judgments are made by musically trained committee members, who presumably are able to discern, to a relatively precise degree, whether or not the candidate is performing with "good intonation." In fact, as both performers and audition evaluation committees are well aware, one of the most important aspects of an orchestral audition for trombonists is accuracy of intonation. As Justin Ross Isenhour states in his dissertation on audition settings, "without exacting attention to correctness of rhythm and accuracy of intonation, style and nuance are of little consequence, especially in an audition setting."[2] Although any statement on the priorities of performance characteristics will likely be heavily focused on fundamental techniques (tone, rhythm, and intonation are

1. Betsy Bright Morgan, e-mail message to author, April 30, 2014.

2. Justin Ross Isenhour, "The Pitched Metronome: An Audition Preparation Resource for Trombonists" (PhD diss., University of South Carolina, 2012), 15.

listed as the three primary reasons for elimination in early rounds of auditions[3]), candidates who cannot play in tune usually are quickly dismissed. Brass players preparing orchestral and band excerpts for solo rounds of professional auditions might consider it sufficient to practice with a tuner to ensure a performance in which the intonation is of a professional quality. Yet, instances of poor intonation in auditions are consistently a factor in the dismissal of candidates.

Certainly some of these faults can be ascribed to improper or inaccurate technical execution, human error, nervousness, and/or insufficient preparation on the whole. However, overlooked is how the environment of the audition (i.e., the specific venues in which auditions take place and their acoustic properties) can affect the perception of intonation in a solo performance. As will become clear throughout this document, a room with long reverberation times can unexpectedly cause two or more tones to sound in harmony, and therefore those sounds are subject to the adjustments made in the just intonation system. Conversely, music in a room with very short reverberation times would be subject to the standards of equal temperament. Critically so, in this case a performance in just intonation will no longer be in tune. Consider this anecdote from Dr. Arthur Jennings, Professor of Trombone at the University of Florida, about a winning audition performance, which correctly took into account the acoustic properties of the audition space:

3. Gugliemo Manfredi, "Perspectives on Auditioning: An Examination of Professional Horn Players on Auditioning" (DMA diss., University of Miami, 2011), 65-66.

> I had [a conversation] a day or two before with James Jenkins.[4] Talking about auditions, he was retelling Rick Stout's[5] story of his successful audition in Cleveland. He was standing backstage in Severance Hall, which is extremely reverberant, listening to the guy ahead of him playing Mozart's "Tuba mirum" and noticing how awfully out of tune it sounded with his own reverb, so when he played he took special care to be in tune with his reverb. James was making the point in that particular excerpt, if those first 7 notes aren't 'dead on' in tune, he and the rest of the committee are simply no longer interested.[6]

As a result of this acoustic and theoretical phenomenon, even for the most technically gifted players, for whom the ability to perform all pitches relative to A4=440 is well-trained, moments of subpar intonation may result if the performer is not aware of the sonic qualities of the particular space within which he or she is auditioning.

In audition settings, trombonists need to constantly evaluate and re-evaluate which of the two tuning systems they will employ throughout the audition, dependent upon the amount of reverberation present in the audition space. In fact, all auditioning wind instrumentalists already operate on this principle, which when simply stated implies that one should play "what sounds right" at all times. We intuitively understand this as a sound in which the tones do not conflict or clash, and are free of a resulting wobbling effect often called *beats.*

It is true, and widely demonstrated, that comprehensive theoretical knowledge and understanding of the just and equal-tempered systems are not needed in order to play in tune. There is a large contingency of wind

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4. James Jenkins is the Principal Tubist for the Jacksonville Symphony Orchestra.

5. Rick Stout is the Second Trombonist for the Cleveland Symphony Orchestra.

6. Arthur Jennings, e-mail message to author, March 24, 2014.

instrumentalists who play in tune (almost) all of the time, despite at most a cursory understanding of intonation theory. In fact, all the musician needs is a trained awareness for the conflicting beats in two sounds, and the technical facility to adjust to that deficiency. To demonstrate, consider this statement from Joseph Muñoz, Second Trombonist of the Tucson Symphony:

> Intonation is good or bad. Over-thinking gets in the way of my own personal playing. My best auditions have been in the "zone" on autopilot. The statement "Can the candidate please play the excerpt again using just intonation?" will never ever be said. The committee is not looking for subtlety in time and intonation, they are looking for those skills to be rock solid. Maybe they are looking for a sensitive player in the final round in terms of intonation, someone that can adjust quickly."[7]

The sentiment expressed by Mr. Muñoz is a widely adopted one. As Betsy Bright Morgan stated, "I've brought this idea up to people in the past…and they've looked at me like I'm taking crazy pills. I'd always get back something like, 'You're either in tune or you're not.'"[8] In addition, Mr. Muñoz is correct in his point that an audition committee would not explicitly ask for a justly tuned performance, and also correct, of course, that intonation is either good or bad, right or wrong. As Mr. Muñoz agrees, what sounds best should simply be considered good intonation, and good intonation is the absence of beats in the sound, and high integrity of spatial relationships between notes; in reality though, the quality by which integrity of spatial relationships is judged is naturally not consistent. Such integrity is dependent upon the presence or absence of harmony, and determines whether or not those beats are present. In other words, level of technical knowledge or awareness notwithstanding,

7. Joseph Muñoz, e-mail message to author, May 8, 2014.

8. Morgan, e-mail message.

if one relies on "what sounds in tune" then he or she will automatically choose the correct system. Perhaps most importantly, Mr. Muñoz makes the observation that in later audition rounds (often played with the entire low brass section), sensitivity to intonation is particularly important, such that adjustments must be made quickly to harmonies created in real-time. Suffice it to say, however, that the fastest intonation adjustment possible would be one that occurred before the note sounded in the first place. In order for the auditioning musician to proactively play in tune, as opposed to retroactively adjusting to intonation issues that are heard in real time, he or she must study orchestral excerpts in a manner that is theoretically flexible, as explained here.

Statement of Problem

For a brass player, harmonies created in solo auditions and the problems and implications that arise for the tuning of said harmonies is of particular importance. As compared to the like in other wind instruments, vocalists, and fixed pitch instruments, subtle changes in brass intonation are the most easily perceived by all listeners, both musicians and non-musicians.[9] The result is that there is not a single truly comprehensive way to prepare solo passages for the purposes of a solo audition. In a passage of loud and adjacent arpeggiations, such as the solo excerpt from the “Tuba mirum” of Mozart’s *Requiem*, the trombonist who has practiced

9. Allen Vurma, Marju Raju and Annika Kuuda, “Does Timbre Effect Pitch?: Estimations by Musicians and Non-Musicians,” *Psychology of Music* 39, no. 3 (2010): 301.

diligently with a tuner, but who is performing in a large and reverberant concert hall, will suddenly find that a perfectly executed arpeggio is now perceived as out of tune by the audition committee. Conversely and crucially so, the trombonist who recognized the theoretical nature of the passage, and thus prepared to play the arpeggio in just intonation, will find that his audience seated in a small and dry room perceives the passage to be out of tune. This is because dry acoustical spaces, which lack the tendency to create reverberation harmonies, are more conducive to performances in equal temperament. Incidentally, because auditors tend to prefer intonation in reverberated settings over dry room settings as a general rule,[10] the previous statement is of critical importance and implication; if the performer has practiced arpeggiated passages consistently in reverberant environments, and made natural but only semi-intentional adjustments that trend toward just intonation, a similar performance in a dry room could be particularly ill-perceived. Conscientious adaptation to environment, therefore, is unavoidably necessary.

Efforts of the pedagogical community, despite the emphasis placed on "good intonation," have widely missed how the performance setting can require variations in the intonation system employed. In Isenhour's dissertation, through which he creates and advocates a "pitched metronome" that provides equal-tempered pitch pulses to accompany commonly asked orchestral excerpts, this point is illustrated through the following language: "there is no resource that provides an audio representation of these test pieces with every note in tune and/or placed precisely

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10. Alan Zabriskie, "Effect of Reverberation and Dynamics on Musicians' Ratings of Choral Tone Quality and Intonation," *Missouri Journal of Research in Music Education* 48 (2011): 58-67.

in time. A set of pitched-metronome files designed to accompany standard audition excerpts would fill that gap."[11] While the statement may be true, the author clearly misses that "every note in tune" is not a reliable constant and can change given acoustic context.

Trombonists preparing to audition receive a list of excerpts from known passages in orchestral music, and then prepare these excerpts to the best of their ability and knowledge. One may examine the trombone and determine that it is equipped to handle all types of tuning challenges; J. Murray Barbour points out that certain instruments, like the unfretted violin and the trombone, have a "flexibility of intonation [which makes] this problem less pressing."[12] However, it is this flexibility which renders perfect intonation technically achievable, and for which it is conquently necessary to strive. Adaptation to environment, therefore, is an inevitable step toward an appropriately high professional standard. In a field which is growing substantially and consistently in competitive quality, the auditioning candidates should be utilizing each and every technique available which can help positively differentiate their performance from that of their peers at the audition. For this reason, it is necessary for every auditioning trombonist to be prepared to perform these excerpts (especially those with particular salient tuning implications) in a variety of sonic situations; in other words, the trombonist must be able to perform adeptly in both the equal-tempered and just intonation systems.

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11. Isenhour, "The Pitched Metronome," 13. Emphasis added.

12. J. Murrary Barbour, *Tuning and Temperament: A Historical Survey* (New York: Da Capo Press, 1972), 8.

CHAPTER 2: INTONATION THEORY

Systems

Throughout musical history, there have been a variety of tuning systems employed by musicians of Western Art Music (and to be fair, there are a great many tuning systems in use amongst the myriad forms of music throughout the globe even today). These include Pythagorean tuning, mean-tone tuning, equal temperament (of multiple varieties), just intonation, and others. This document focuses only on the two systems which are most apropos to the performance of Western symphonic music, just intonation and twelve-tone equal temperament.

At the beginning of a concert, a symphony orchestra tunes to an A4 pitch (usually between 440 Hz and 444 Hz). With that single oboe tone, they are conquently setting the exact frequency references for all tones employed throughout the concert, using the twelve-tone equal-tempered scale (from this point onward, “equal temperament” will refer to the common twelve-tone variety). However, throughout the duration of the performance, in each individual moment of harmony the performers will (sometimes consciously, sometimes not) adjust individual tones to create harmonies that are as in tune as possible, using the standards of just intonation. Together, these two systems work to make art music as we know it possible. Equal temperament makes the development of sonata form possible, with its tolerance of multiple key centers. Conversely, just intonation is responsible for dictating how individual harmonic verticalities can be performed in the most resonant and physically symmetrical way possible, and is a large part of what an audience is likely to consider the best possible orchestral performances, whether they and the musicians know it or not. These systems are both complementary and contradictory, as will be elucidated below.

Equal Temperament

An understanding of the fundamentals of the two systems of just and equal temperaments is needed, precisely because they are barely directly compatible. For equal-tempered instruments like the harp, piano, guitar, keyboard percussion, etc., the octave is divided into twelve equidistant semitones such that the system works excellently for horizontal, or non-simultaneous, tones. As is mathematically natural, there is a 100% difference between the frequency of one pitch and the frequency of a pitch a semitone away in either direction. However, musical frequencies (measured in Hertz) change logarithmically, not linearly, and in order to combat this issue for practical purposes, we define the distance between each semitone in linear pieces called *cents*, which are simply 1/100 of the total frequency difference between the two tones. As a result of the partitioning of the octave into equal pieces, all harmonies (with the singular exception of the octave) are out of tune. However these harmonic malfunctions are consistent in all keys, and consequently they are ignored and accepted by the ear; for example, a C major triad is just as poorly tuned as an E♭ major triad. The primary benefit is the ability to perform all harmonies equally, albeit not in tune, in any of the twelve aurally unique musical keys. In other words, an instrument does not have to be retuned for each individual key, and can successfully perform with identical intonation in all keys. Furthermore, most instruments which employ equal-tempered tuning are not able to sustain tones without immediate decay. Due to this characteristic, imperfectly tuned harmonies are more difficult to distinguish and less abrasive to the listener. Although this factor facilitates acceptance of equal temperament, it is not applicable to aerophones, for which the ability to sustain tones renders the intonation deficiencies more readily apparent.

Just Intonation

By contrast, the just intonation system of temperament adjusts harmony to conform to the natural whole-integer frequency ratios of the harmonic series, and is therefore the system for vertical, or simultaneous, tones. In the context of tones that sound together, “what sounds right” is now dependent upon the degree to which the sounded pitches “line up”, both mathematically and physically speaking. For example, a perfect fifth occurs when the frequency ratio of the two tones is 3:2; given a tone sounding at 200 Hz, a justly tuned perfect fifth above will sound at 300 Hz. The just intonation system is therefore not compatible with equal temperament. Pitch adjustments are always necessary when playing harmony, and the following is one example why: when we tune our instruments to A4=440, the E one perfect fifth above occurs at 659.25 Hz, not at 660 Hz. The equal spacing of semi-tones results in a slight compression of the interval, and therefore the E5 will need to be slightly raised in order to create a relationship that is at the proper 3:2 frequency ratio. This issue applies to all tones a perfect fifth from each other on an equal-tempered instrument. Although chords with multiple extensions beyond the triad incur more complex relationships, for which some exceptions to this rule are made, the goal is always to produce sounds for which the relative frequencies are the most complementary, otherwise known as *additive*.

Use in Practice

Therefore, an attempt to universally qualify pitches as in tune or out of tune, as one would be doing by using a chromatic tuner to practice orchestral excerpts, is misguided, futile, and essentially akin to fitting a square peg in a round hole. The only two harmonies that the two systems have in common (that is, the situation in which the literal frequencies are identical in both systems) are octave and unison harmonies. However it is at this “pivot point” that Western Art Music operates; the two systems “need each other” in order for Western Art Music to function the way that it does. A symphony orchestra, as a salient example, takes the “best of both worlds” by using the semitone spacing standards delineated by equal temperament to fundamentally define pitches relative to A4=440. Then, on the local level of individual vertical harmonies, adjustments are executed to make these harmonies as consonant as possible (within the constraints of human ability and individual knowledge, of course). Simply put, a world-class performance of any piece of

Western Art Music relies entirely on a marriage of both systems, and simply could not be performed at a high level otherwise.

A consideration that is both a virtue and a limitation in the scope of this research is that college wind instrumentalists have been found to be the class of musicians that deviate the least from equal temperament in performances.[13] However, while all fixed-pitch Western instruments are adjusted in the tuning system of twelve-tone equal temperament, the pitch of brass instruments is movable and therefore a candidate for just intonation as well as equal temperament. It is certainly true that adjustments are made naturally and instinctively by many professional musicians, but proactivity in these corrections is crucial for professional musicians. Meiko Kanno states this tenet eloquently:

> When the performer plays a melody and perceives a small deviation in pitch, she corrects it by adjusting the note itself or the note that follows immediately. The characteristic intonation imbedded in the laws of acoustics informs the performer of desired target values and thus a *mechanism of feedback* operates whenever a pitch deviation occurs. Such pitch deviation *can be intentional*.[14]

This study is presently and henceforth exclusively concerned with the trombone, for which, with its ability to adjust pitch very quickly and accurately, intonation expertise is particularly expected.

For the purposes of this study, in which the relevant judgments in auditions are made aurally, good intonation is defined as it would be in a Western Art Music

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13. Dennis Ballard, "Relationships Between College-level Wind Instrumentalists' Achievement in Intonation Perception and Performance," *Bulletin of the Council for Research in Music Education* 187 (2011): 20.

14. Meiko Kanno, "Thoughts on How to Play in Tune: Pitch and Intonation," *Contemporary Music Review* 22, no. 1/2 (2003): 3. Emphasis added.

context. In other words, as aforementioned, good intonation is context dependent. When two pitches are played in isolation, not simultaneously, the judgment thereof is made in an equal-tempered system; the frequencies of the two tones should be perfectly spaced in relation to A4=440, as defined by the equal partitioning of an octave. When two pitches sound simultaneously in harmony, their judgment is made in the just intonation system; the two pitches should conform as closely as possible to frequency ratios of small and whole integers (aurally perceived as having "no beats"). The resulting sound is such that there is a "strongly implied preference for the simplest ratios compatible with a given musical purpose."[15] In other words, sound waves which are complementary to one another, in terms of the mathematical relationship of their respective lengths, are always given priority when performing in just intonation. This is true regardless of the complexity of the resulting harmonies.

15. David Doty, *The Just Intonation Primer: An Introduction to the Theory and Practice of Just Intonation* (San Francisco: Just Intonation Network, 1994), 1.

CHAPTER 3: REVERBERATION SCIENCE AND ACOUSTICS

Definitions

Any instrumentalist attempting to apply the techniques posited henceforth in this paper is likely to immediately recognize the importance of a method or instrument through which one could assess the reverberation times existing in a given space. However, before embarking on that task, an overview of the fundamentals of acoustic science is apropos.

It is important to develop a cursory understanding of the various elements that make up what we call "music," and see how the various definitions interact with one another. *Sound* is defined as "a wave motion in air or other elastic media."[16] The pitch of a sound is measured in the quantity labeled *frequency*, which is a measurement of the cycles per second (hertz) at which the sound waves are oscillating. Faster oscillations, or higher frequencies, are analogous to higher perceived *musical pitches*, and vice versa. As a reference, the generally established range for human hearing is between 20 Hz and 20,000 Hz (20 kHz).[17]

The volume of the sound (one of the critical elements for this thesis, as a starting volume will be a primary determining factor for whether a harmony will occur or not) is measured most commonly in *decibels*, which are a "logarithmic way

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16. F. Alton Everest, *The Master Handbook of Acoustics* (New York: Mc-Graw Hill, 2001), 1.

17. Jeffrey Hass, "What is Frequency?" Indiana University Center for Electronic and Computer Music, accessed May 12, 2014, http://www.indiana.edu/~emusic/acoustics/frequency.htm.

of describing" sound pressure.[18] This means that decibels do not directly equal sound pressure, measured in *pascals*, but are a way of representing pressure relative to a set reference point. In the case of sound volume, this reference (a level of 0dB) is set to 20 micropascals, which is the lowest pressure that can be heard by a young and healthy human being.[19] The reason that we use decibels to describe pressure is because the relationship is not exact, and decibels are "a convenient way of handling the billion-fold range of sound pressures to which the ear is sensitive without getting bogged down in long strings of zeros."[20] See Appendix A, which shows the estimated decibel levels of some common sounds, in order to get a more practical sense of decibels and their real-life perceived equivalents. Musical instruments create their characteristic sounds in different ways: by vibrations of a string, stretched membrane (snare, timpani, etc.), air, wood, and a variety of other substances. To elaborate briefly on the instrument relative to this study, consider this quote from Alton Everest, a proclaimed "master" of acoustic science:

> If air is enclosed in a narrow pipe closed at both ends, the fundamental (twice the length of the pipe) and all its harmonics will be formed. Wind instruments form their sounds this way; the length of the column of air is continuously varied, as in the slide trombone, or in jumps as in the trumpet or French [sic] horn, or by opening and closing holes along its length as in the saxophone, flute, clarinet, and oboe.[21]

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18. Joe Wolfe, "dB: What is a Decibel?," UNSW School of Physics, Sydney Australia, accessed May 12, 2014, http://www.animations.physics.unsw.edu.au/jw/dB.htm.

19. Everest, *Master Handbook*, 28.

20. Ibid., 23.

21. Ibid., 101.

Regardless of the individual methods used to create sounds by instruments of the symphony orchestra, it is always the case that the cause of sound is *vibration*, from which vibrating waves propagate through a medium (usually air, when listening to music!) and are perceived and interpreted by the human ear.

This document is primarily concerned with the acoustic phenomena of *reverberation*, which is "the sum of the reflected sound energy from the surfaces of [an] enclosure."[22] In simpler terms, reverberation is the collected sense of a sound perceived when the sound "bounces back" off of walls, ceilings, and floors. *Reverberation time*, a critical element of the thesis of this document, is the "time required for the sound in a room to decay 60dB."[23] The most common way of measuring reverberation time is through a prediction equation arising from the work of Wallace Clement Sabine, which remains the standard by which reverberation times are measured today:

> W.C. Sabine, the Harvard pioneer in acoustics who introduced this concept, used a portable wind-chest and organ pipes as a sound source, a stopwatch, and a pair of keen ears to measure the time from the interruption of the source to inaudibility. Today, we have better technical measuring facilities, but we can only refine our understanding of the basic concept Sabine gave us.[24]

Sabine conducted the reverberation time experiment in several different spaces, then analyzed the data he collected and developed his reverberation time equation. Known simply as the "Sabine Equation," it is written as:

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22. Carl R. Nave, "Reverberation Time; Physics 4060: Acoustics Laboratory," HyperPhysics, accessed May 12, 2014, http://hyperphysics.phy-astr.gsu.edu/hbase/ph4060/p406ex7.html.

23. Everest, *Master Handbook*, 135.

24. Ibid., 135.

Where:
RT60 = reverberation time (seconds)
V = volume of room (cubic feet)
S = total surface area of room (square feet)
a = average absorption coefficient of room surfaces

$$\boldsymbol{RT60 = \frac{0.049V}{Sa}}$$

This definition of reverberation time (labelled RT60) is arbitrary, but has some rationale in a practical situation, which, coincidentally or perhaps not, is directly related to the present topic. The performing level of the symphony orchestra is (or, in any case, was) considered to be around 40dB at softest and 100dB at loudest volumes. In addition, the background noise level in an auditorium is generally considered to be around 40dB. Therefore, RT60 describes the amount of time which it would take for the loudest sounds of a symphony orchestra to diminish to the level of background noise in the concert hall.[25]

Reverberation in Concert Halls

Reverberation times are the main criteria for determining whether a room is acoustically dry (very little reverberation) or wet (lots of reverberation).[26] The dryness or wetness of an acoustic space is not set to any standard, but suffice it to

25. Carl R. Nave, "Acoustics Laboratory."

26. Jeffrey Hass, "What is Reverberation (Reverb)?" Indiana University Center for Electronic and Computer Music, accessed May 12, 2014, http://www.indiana.edu/~emusic/etext/acoustics/chapter1_reverb.shtml.

say that reverberation times under .5 seconds would likely be universally considered dry, while a time over 3 seconds would be considered wet. While standards are lacking for the subjective quality of reverberation, there does exist some consensus as to the ideal reverberation times of various spaces, based on their function. For example, the orchestral concert hall is generally considered to have ideal acoustics if the room has "a reverberation time between 1.8 and 2.2 seconds at mid-frequencies."[27] However, a classroom setting, one which is somewhat common for school and lower-tier orchestral auditions, would be drastically different: "Around two seconds is desirable for a medium-sized, general purpose auditorium that is to be used for both speech and music. A classroom should be much shorter, less than a second."[28] In addition, some cathedrals, such as the Notre Dame Cathedral in Paris, can have reverberation times of nearly eight seconds. An audition for a professional performance ensemble (at which orchestral excerpts would be played) can take place in a wide variety of acoustic spaces, ranging from a small classroom to a large auditorium, concert hall, or cathedral. Clearly the range of acoustic settings is wide, and it is consequently self-evident that while a solo excerpt is being performed the reverberation of a played tone will occasionally be long enough to result in harmonies between the reverberating tone just performed and the tone currently being produced by the auditioning musician. These incidental harmonies are aurally judged by committee members as all harmonies are

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27. Jessica Hall, "Reverberation," Concert Hall Acoustics, accessed October 13, 2013, http://www.concerthalls.unomaha.edu/discussion/reverb.htm.

28. Carl R. Nave, "Reverberation Time," HyperPhysics, accessed October 13, 2013, http://hyperphysics.phy-astr.gsu.edu/hbase/acoustic/revtim.html.

inevitably judged, by the presence or absence of "beats" in the sound (related inextricably to just intonation theory). This is in contrast to the way that individual tones are judged, which simply relies on precisely equal spacing of tones (100 cents per semitone). In other words, because heavy reverberation can sympathetically cause the notes played to interact simultaneously in a harmonic context, passages which were previously performed successfully in an equal-tempered system will now adversely interact in the just intonation system.

However, it must be noted that reverberation does not occur evenly at all frequencies, and generally the reverberation time for low frequencies[29] is longer than that of middle and high frequencies, typically on the order of 40%.[30] This occurs naturally as well as artificially. Certain choices of material for room construction will influence reverberation times of low frequencies; for example, wood tends to selectively absorb high frequencies, leaving longer reverberation times in the low frequencies, while thin paneling on studs performs oppositely, and should not be used in musical spaces. Auditoria are often designed specifically so that reverberation times are longer in the lower ranges, because this gives a "natural-sounding bass boost to sound in the rear" of the space.[31] In fact, some of the most celebrated halls in the world have longer reverberation times in lower frequencies, including Carnegie Hall in New York and the Symphony Hall in

29. Although often referenced, there is no standard definition for "low," "middle," and "high" frequencies. In this paper, low frequencies will be defined as frequencies less than 1000 Hz.

30. John Backus, *The Acoustical Foundations of Music*, 2nd Ed. (New York: W.W. Norton, 1977), 151-156.

31. Carl R. Nave, "Longer Reverberation for Lows," HyperPhysics, accessed May 05, 2014, http://hyperphysics.phy-astr.gsu.edu/hbase/acoustic/revlow.html.

Boston.[32] This is relevant to this study, as the orchestral trombone literature only spans the range of 55-700 Hz (A1-F5), and furthermore is most typically found within the range of 82-523 Hz (E2-C5). This frequency range is within the range for low frequencies, and therefore when assessing reverberation time for the purposes of intonation, the trombonist should add a "bonus" on the order of roughly 40% to the known, official reverberation time of the space. However, as will be elucidated shortly, in many cases it will be most practical to simply assess the acoustics of the space on site and in person, whilst playing the trombone. Therefore, if a reverberation time were to be calculated in person, it would already take into account the trombone "bonus," per se.

Predicting Reverberation Times

Predicting reverberation time mathematically can be difficult, due to the nonlinear nature of some spaces. Although architectural design makes a concerted effort otherwise, certain auditoria are non-diffuse (the properties of the sound are not the same in all discrete locations within the space). We know this intuitively from our experiences attending orchestra concerts in such spaces, as certain seating locations are considered "prime" for hearing different elements of the orchestra; a trombonist attending the concert, and interested in hearing as much trombone as possible, might sit in the upper left mezzanine of the hall, while the conductor interested in hearing a homogeneous sound would prefer the center of the orchestra

32. Ibid.

floor. In fact, non-diffuse spaces are not in any way uncommon, and the standard Sabine equation for calculating reverberation time as a function of room dimensions is not accurate in this condition.[33] As an example, the engineers who built the Gottingen Stadthalle, a 1250-person multi-purpose concert hall built in 1964 in Germany, expected the reverberation time to be 1.6 seconds. However, when reverberation times were observed and calculated for the first time, they were surprised to find an average reverberation time of 2.0 seconds, a miscalculation on the order of 25%.[34] This shows that even mathematical preparations routinely fail at precisely determining reverberation time.

33. Barron, Mike. "Non-linear Decays in Simple Spaces and their Possible Exploitation." *Proceedings of the Institute of Acoustics.* Vol 34, Pt 2, 2011, 1.

34. Ibid., 7.

CHAPTER 4: APPLYING THEORY TO PRACTICE

Finally, given this basic information on acoustics and acoustic science, a question is naturally and immediately begged: How can the musician know, accurately, whether to perform the justly intoned version of the excerpt or the equal-tempered version? An assessment of this question must always account for three interactive and critical factors: 1) the volume at which the first note is played; 2) the amount of time between the end of the first note and the beginning of the harmonic note in question (not always the very next note; see the *Excerpt Analyses* for more detail); and 3) the reverberation time of the performance space. Two of the three components of the performance are within the active control of the performer (volume and tempo), while the remaining one is not internally controllable and can be difficult to ascertain (reverberation time).

Determining Reverberation Time

There are a variety of methods, of varying levels of practicality, through which a trombonist could assess the reverberation time of the hall and make a decision regarding just or equal temperaments; suffice it to say that the majority of readers will find the final option the most usable in an actual audition context.

Should the musician wish to take the most intellectually rigorous approach in which accuracy is guaranteed, the actual reverberation time of the audition space must be known. Of course, the simplest strategy, and the one with the smallest margin of error, would be to discover, through a conversation with the hall's engineer or technical workers, the actual measured reverberation time of the space. However, this simple strategy might prove to be the most cumbersome and challenging, as this information may not be readily available, and assumes that the trombonist is able to get in contact with the appropriate person. Secondarily, yet significantly less practical, would be to attempt to ascertain the exact dimensions and acoustic properties of the audition space, learn and apply the Walter Sabine reverberation prediction equation, and then make his or her decision. For obvious reasons, this is time consuming and requires significant outside knowledge, and is generally unfeasible. Finally, however, one could purchase a professional grade sound level meter (or download a smartphone application) which can measure the reverberation time of a room. Sound level meters are widely available but at a cost which would likely be considered prohibitive ($500-$2000). Smartphone applications however, like the program AudioTool by the Bonfinit Corporation, can be purchased for under $10. Although accuracy is naturally somewhat less reliable with a phone application, this particular application has been well reviewed by sound engineers, and received a recommendation from "Sound and Vision" Magazine, showing that phone applications such as this one have improved vastly in recent years as legitimate tools. This still leaves the issue of having time to enter the audition space in silence and perform a test of the reverberation time, which certainly would pose a dubious challenge.

Empirical Calculation with Known Reverberation Time

These challenges notwithstanding, if the performer were able to learn the actual reverberation time of the hall, then the decision of which system to employ could be easily calculated empirically. Included with this document is a calculator (Appendix B) devised by the author which incorporates the three operative elements of the performance, and simply returns a suggestion for performance ("Equal Temperament" or "Just Intonation"). The expression, which simply determines the ending volume of a reverberated note based on given contextual parameters, is shown below:

Where:
v = volume of played tone (decibels)
b = beats in between tones in question (integer)
t = tempo (bpm) of performance
T = total time in between operative notes (seconds)
R = reverberation time of space (seconds)

$$\boldsymbol{v} - (\boldsymbol{T} \div \boldsymbol{R} * \mathbf{60})$$

In addition, if the time in between notes is not known or has not been calculated, it can be calculated as a function of tempo (bpm) and total beats in between operative notes:

$$\boldsymbol{v} - ((\boldsymbol{b} \div (\boldsymbol{t} \div \mathbf{60})) \div \boldsymbol{R} * \mathbf{60})$$

If the output of the expression is less than "40" (the background noise level of the average auditorium is considered to be roughly 40dB) the "solution" is to perform with *equal temperament*. Conversely, if the output is greater than "40," and would be therefore heard at the time that the note in question is sounded, the result would be to perform with *just intonation.*

Unfortunately, for the majority of cases, the actual reverberation time will be difficult to determine. To solve this problem, the musician could consult Appendix C, which lists a variety of reverberation times for different types of spaces, including a variety of concert halls for which the reverberation time is public knowledge. In addition, the shape of the concert hall, as observed in real time on location can be considered, as research has demonstrated that differing shapes of concert halls will somewhat predictably affect the acoustics of the hall (historically speaking, the "shoebox" shape is considered traditionally ideal).[35] In fact, differences of shape can contribute between five and twenty percent of the absorption coefficient,[36] a critical element of the Sabine Equation.

Finally, and almost certainly the most practical and likely to be employed, a simple value judgment should be made by the performer on the reverberation properties of the audition space. Simply put, if you can still hear your sound when you start the next note, then harmonic tuning rules will apply. In orchestral auditions, the performer often has the opportunity to play briefly before his or her audition performance begins. Although there is some controversy amongst pedagogues and performers as to whether any notes should be played in the audition setting that are not actually part of the audition (the prevailing attitude to the contrary is that all notes are judged, not just the notes in the excerpts

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35. Yan Zhang, "A Method to Predict Reverberation Time in Concert Hall Preliminary Design State" (PhD diss., Georgia Institute of Technology, 2005), 69.

36. Ibid., 73.

themselves), many players do take this approach. Michael Becker, Principal Trombone of the Tucson Symphony Orchestra and a regular performer with the Chicago Symphony Orchestra, has noticed in one of his own professional auditions that a reverberation effect caused him to sound out of tune. From this experience, Mr. Becker now understands the implications and accounts for the effect that acoustics that can have on a performance, and advocates that "You should always play a few test notes before you start your audition to see how the acoustics are in the hall. Then you'll know how much to adjust your intonation."[37]

While not the technically sound approach, and having the greatest margin for error, this technique has the great advantage of requiring no extra time or knowledge on behalf of the performer in order to be employed, and is by far the most practically feasible option for an auditioning trombonist.

37. Michael Becker, e-mail message to author, April 22, 2014.

CHAPTER 5: REVIEW OF SCHOLARLY LITERATURE

Much has been written on the subject areas that this study will combine (including just intonation theory, instrumental techniques to address intonation difficulties, the acoustics of concert halls, etc.). Following a perusal of the scholarly literature on these topics, and exhaustive searches through research databases, it appears that a study that combines just intonation theory with live orchestral auditions, and the reverberation consequences that might result, is unique. However, much can be drawn from the content of the existing sources in order to combine the present intents with them. They are presented here organized by topic content.

Intonation Theory and History

Murray Barbour's book, *Tuning and Temperament: A Historical Survey*, is an adaptation of his dissertation, and is an excellent source that collects and presents information on the various tuning systems which have been employed in music performance, both present and past. The book has a historical emphasis to it, but also presents the theoretical nature of each tuning system in clear detail. Critically, Barbour includes a final section on intonation practices "today," as well as remarks on the various tendencies of instruments of the symphony orchestra, a section which is quite well adapted to the present study.

The Just Intonation Primer is an excellent resource, written by David Doty, which goes into more depth on just intonation theory specifically, and is intended as an introductory resource for those that might be new to alternative tuning systems. This book is significantly more focused than Barbour's, and even includes a short section that specifically touts the trombone as an instrument with critical implications in the just intonation system. As Doty notes, the trombone "produces a timbre with stable harmonic partials, and hence [has] the ability to precisely tune simple-ratio intervals."[38] Said another way, the sound of the trombone, and especially multiple trombones, is one for which judgments of intonation are particular easy to apply. This statement is in line with my projection that interacting reverberations are of particular consequence and salience to trombonists.

An article by Ll. S. Lloyd which appeared in *Music and Letters* in 1940, entitled "The Myth of Equal Temperament," is a philosophical exposition on the musical fallout of equal temperament. Lloyd expounds upon the variety of problems that have arisen since the advent of equal temperament in keyboard instruments, including a "detriment to their quality of tone"[39] that pervades musical listeners (and presumably, has been more and more a part of our perception of tone since the date of this publication). This article is particularly relevant to a section of the paper that discusses the philosophy of purposefully mediating intonation to appeal to a variety of sensibilities.

38. Doty, *Just Intonation Primer,* 76.

39. Ll. S. Lloyd, "The Myth of Equal Temperament," *Music and Letters* 21, no 4 (1940): 348.

The Science of Reverberation and Concert Hall Acoustics

The most useful resources for learning about the basics of concert hall acoustics proved to be two widely known comprehensive texts. These included a renowned F. Alton Everest text, *The Master Handbook of Acoustics,* and John Backus's *The Acoustical Foundations of Music.* Both sources are extremely well organized and cleanly written, providing a wealth of visual aids, basic definitions, and a general view of acoustics that holistically describes given phenomena. Both sources touch on tuning systems, instrumental sound production, concert hall idiosyncrasies, and mathematical manifestations of intuitively known realities.

Although his work focused on developing a prediction model, Yan Zhang's dissertation, "A Method to Predict Reverberation Time in Concert Hall Preliminary Design Stage," contains highly useful introductions and reviews of basic reverberation constructs. As this dissertation was completed for a PhD in Architecture, it is thorough in its examination of the mathematics of this science, and it is a critically important and credible resource for my study. His opening sections, which focus on concert hall design and the myths, precedents, and science that surround it, offer a strongly objective view of acoustics as they apply to music-making in large spaces. In addition, Zhang includes a detailed analysis of ideal reverberation times for various genres of music, even differentiating between Classical and Romantic styles. The wealth of visuals and graphic representations has assisted me in understanding these basic concepts, and will deeply inform this study going forward.

Two websites published by major universities were explored to gain a better understanding of the physics of reverberation, as well as a basic outline of the acoustics of concert halls. Jessica Hall's page "Reverberation" (University of Nebraska–Omaha) provided basic definitions for the science of reverberation as well as some information on the standards of concert halls (with examples from famous spaces), while Carl Nave's "Reverberation Time" includes more in-depth formulas and online calculators for the user to gain a deeper understanding of reverberation acoustics.

Intonation in Professional Auditions

Tyrone Grieve's article that appeared in *The Instrumentalist* entitled "Preparing for Auditions" is essentially a primer for student violinists in the nature and expectations of orchestral auditions. Although primarily suited for string players and highly focused on technique, Grieve's section on the importance of intonation, especially in an audition setting, does reiterate this seemingly universal sentiment; his article is an addition to a large body of evidence that suggests that intonation is widely considered a top factor in audition elimination.

In his dissertation for the University of Miami, Gugliemo Manfredi gives a general outline of the landscape of professional orchestral auditions for hornists, and its recent date of publication renders it particularly germane to this study. His work includes insights on the preparation for auditions, as well as audition procedures and expectations. In addition, Manfredi includes transcripts of interviews conducted with audition committee members, from which I will be able to draw pertinent information. His paper also substantiates that intonation is one of the most common reasons for elimination in professional auditions.

Strategies for the Practice of Intonation Techniques

Justin Ross Isenhour advocates the use of a metronome which tracks both pulse and pitch in his dissertation, "The Pitched Metronome: An Audition Preparation Resource for Trombonists." The author contends that a sound file can be made that performs only the pitches that occur on the downbeats of each measure of orchestral excerpts, which would hypothetically aid trombonists in efficient practice of those excerpts. By nature, this effort would completely ignore any and all just intonation considerations, and suggests that the trombonists learn the excerpts only in the equal-tempered system. Similar to the eventual presentation of this study, Isenhour includes customized transcriptions of the excerpts and a discussion of the rhythmic and tonal difficulties of each. Although his intents are not fully aligned with this study, his pitched metronome and sound files may be a valuable resource specifically for practice of an equal-tempered performance.

Another source in technical strategies is the dissertation of Douglas Smith, which is considerably larger and deeper in scope than that of Isenhour. Instead of focusing on a single and novel new way to practice intonation, Smith delves into a wide variety of practices. His categorization of research into the area of instrumental intonation into four categories (performance patterns and predisposition, stimulus effects, contextual effects, and interventions) serves as a guide to technical practice in intonation. His work focuses on younger students, however it is, in the author's opinion, self-evident that exercises for children are often powerfully recollective for adults who are revisiting a fundamental area of technique, such as the one presently studied.

Meiko Kanno, a professional violinist, published a scholarly article entitled "Thoughts on How to Play In Tune: Pitch and Intonation," in which she shares some excellent and thought-provoking comments on how tuning can be used to expressively affect a musical performance. Kanno as well as other authors have noted that both string instruments and brass instruments are similar in the realm of just intonation, as their highly modular mechanisms of performance allow for a wide variety of variances.

Intonation Studies as They Relate to Timbre and Reverberation

An article by a collection of three authors entitled "Does Timbre Affect Pitch?" addresses a key component of this study, which is the presumption that the considerations being discussed are of particular importance to trombonists. Vurma, Raju, and Kuuda devised a series of tests to determine how the subjective judgments of a group of subjects varied based on the timbre of the instrument they were hearing. In addition, they describe some actual musical situations in which a timbral change might cause a conflict, which would then require some adjustment by the performer.

Alan Zabrieski's article on the "Effect of Reverberation and Dynamics on Musicians' Ratings of Choral Quality and Intonation" is one that is perhaps the closest to the present study in terms of intention. In his work, participants in a survey listened to recordings that were electronically altered to simulate different volume and reverberation environments. His study, however, focused on how the participants perceived the intonation of the recordings when reverberation was added (not surprisingly, they nearly universally preferred reverberant recordings over non-reverberant recordings), not necessarily on how the tones tonally interacted at various levels of reverberation.

Dennis Ballard's article on the "Relationships Between College-Level Instrumentalists' Achievement in Intonation Perception and Performance" focused on comparing perceptual and performance tasks in multiple tuning conditions. Like Meiko Kanno, Ballard notes that timbre can have significant effects on the perception of intonation. Of particular importance is the statement that musicians tend to show a "preference for the tuning context to which they have had the most exposure."[40] There are some critical implications to this fact, which includes the possibility that some intonation variances should be mediated in order to appease the variety of musicians that typically sit on orchestral audition committees.

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40. Ballard, "Intonation Perception and Performance," 3.

Indices, Annotations, and Collections of Orchestral Trombone Excerpts

In complement to my personal knowledge, experience, and education, as well as the advisement of my professional colleagues and advisors, I have at my disposal a variety of indexes and annotated guides to the most commonly asked orchestral excerpts at trombone auditions. For this study I have a wealth of options that exist online and in print that perform similar duties. These non-exclusively include two articles that have appeared in the scholarly journal for trombone studies (*International Trombone Association Journal*), and two published books: an index by Carolyn Rabson and an annotated guide by James E. Roberts. Finally, a dissertation by Seth Vatt delineates in detail one of the more popular websites for trombone excerpts, TromboneExcerpts.org. His dissertation details the content, development thereof, and technical design of the website, in an effort to supplement and guide trombonists to the resources that the website provides.

Generally speaking, these collections serve the purpose to collect, organize, and expound popular trombone excerpts, giving some historical context, common performance faults (which, of course, often focus on intonation), and some information on performance variations that can be undertaken. These sources will be useful to my project in two ways: as a guide to choosing the excerpts for analysis, and as a supplement to any technical or performing issues which I may overlook that impact intonation considerations.

Similarly, a series of articles entitled "Orchestral Excerpt Class" written by Dennis Bubert, also for the *International Trombone Journal*, offer both in-depth analysis as well as commentary and practice suggestions by leading professional players. These articles have a similar usefulness with regard to indexing of popular excerpts, and will add to the body of works listed above in assisting the analysis portion of my study.

CHAPTER 6: INTRODUCTION TO EXCERPT ANALYSES

Included with this document, as the centerpiece for practical application of these concepts, are ten intonation analyses of commonly requested orchestral excerpts for trombone. These analyses show the tuning adjustments that should be made by the musicians in an acoustic environment that is sufficiently reverberant (see the previous sections for an introduction and guide to application). Appendix D presents the tuning adjustments of a variety of common chords and single intervals, for reference. As described previously, in order to prepare the excerpt for an environment which did not meet the threshold for a justly intoned performance, musicians should prepare to the best of their ability in equal temperament, employing whichever method they consider most apropos (using a chromatic tuner, recording oneself, playing along with a tuned piano or organ, etc.).

Contents of and Definitions Pertaining to the Analyses

Each excerpt was transcribed from a public domain or personally purchased edition into a music notation software program. The excerpts included in this document are not to be reproduced or distributed, and should not be used as a substitute for the acquisition of a personal copy. In addition, for this reason, the transcriptions do not include any expressive markings or instructions, dynamics, or other elements that would be found in a printed edition. The transcription gives only the pitches and rhythm, and their necessary adjustments to perform the passage with just intonation. It is intended that the trombonist who reads this document use the analyses to inform his or her preparation for an audition with a symphony orchestra or other professional ensemble or competition for which these excerpts are asked.

Here it is extremely important to note one of the most critical factors that affects this document: the harmonies created through a solo audition in a reverberant room may or may not be the same as the harmonies that actually underlie the music in full score. In the solo audition, the harmonies dealt with are the *present ones*, as created by the reverberation of the room. This means that the only harmonies in consideration are the intervals in direct succession within the excerpt. However, these harmonies may not reflect the aggregate sounds of the orchestra when the music is performed with all parts simultaneously. In addition, as the reverberated harmonies are only those in direct succession, occasionally the played harmonies are also not the functional harmony, even within the excerpt itself. This will be demonstrated several times in the analyses.

As a generic example in isolation, consider the possibility of playing a single minor third in a solo round of an audition. If the room is sufficiently dry, the tones would both be played at frequencies that relate perfectly to A4=440 (see Appendix E, which gives the actual frequencies for each pitch in the musical range of the trombone, as they relate to A4=440). However, if enough reverberation is present, the two tones should be tuned as such, with the upper tone raised by sixteen cents. Furthermore, it is entirely possible that the trombone part is simply outlining the fifth and seventh of a dominant harmony which the orchestra would be playing at large in a live performance. The tuning of these two tones would then be radically different: raised two cents for the fifth and lowered thirty-one cents for the seventh, in relation to an equal-tempered root tone. In fairness, it should be noted that some musicians suggest that committee members, particularly conductors, have the ability and penchant for hearing other orchestral parts in their heads during the audition. However, due to the fact that individual listening talents of the audition committee cannot possibly be comprehensively known or totally accounted for, this paper will ignore any potential existence of these “phantom tones” in the minds of the committee. Phantom-tones notwithstanding, it is therefore self-evident that in fact there are potentially *three* ways that a given musical passage can be prepared and best performed, given three possible tuning contexts (a solo performance with little or no reverberation, a solo performance with sufficient reverberation, and a performance with additional musical parts from the ones being played by the individual). In fact, it would be advisable for the trombonist to be aware of this third context for the purposes of the final round of the audition. The final round is usually played with the rest of the low-brass section of the orchestra, and the excerpts included are sometimes not explicitly known. However, the paper will consider only solo performance contexts.

The definition of the “adjustment” of a given pitch is defined as the change in cents in relation to an A4 tuned at 440 Hz. As previously discussed, a cent is 1/100 of the change in frequency between any given pitch and the semi-tone pitch most adjacent. In other words, one cent lower than A4 is 1% closer to A♭4, and therefore the distance between A♭4 and an A4 that is one cent flat is only ninety-nine percent of the distance that it "should be," if the integrity of the tone spacing were intact. When A4 is tuned to 440 Hz, an equal-tempered system then categorically defines all pitches above and below it (again, see Appendix E). In the analyses, tones will be marked with a number and a plus or minus sign, for example "-14," indicating the total number of cents that the pitch should be lowered or raised. In reality, the adjustments are not simply whole numbers of course, but more precise calculations that logarithmically reflect the just frequency ratio (for example, the adjustment for a major third is actually −13.69 cents). However, for the purposes of practicality, all adjustments have been rounded to the nearest whole integer. In order to practice these adjustments empirically, the trombonist should use a chromatic tuner, which displays changes in cents relative to a set reference point in equal temperament (most tuners can be calibrated to change the reference frequency as appropriate; for example, some orchestras tune to an A4 at a frequency other than 440 Hz, for timbral and/or traditional purposes).

In addition, the estimated time between notes in question is also given in the analysis for any example in which the operative tones are separated by either rest or other tones. Given a presumed or calculated reverberation time of the audition space (see the section on reverberation), this information is critical for determining whether or not to adjust the tone. If the reverberation time of the space is longer than the time given in the analyses, then the first note will still be sounding when the second note is played (also dependent upon starting volume, of course, which can be incorporated with the calculator also mentioned in the section on reverberation). While the time is given for a more exacting approach, for more practical purposes the performer should simply listen attentively to the "liveness" of the space as he or she is playing, and make the decision at that time.

In the analyses, only triadic or triad-like material is adjusted for pitch. The author suggests that the performer avoid attempting to adjust tones in strictly scalar material, as complications can arise that are difficult to reconcile. Although there are, strictly speaking, adjustments for every tone in the major scale, these adjustments relate to the tonic tone, presuming that it is sounding alongside each degree of the scale. In solo excerpt material, although in many cases the music is fully diatonic or nearly so (see *Lohengrin* below), the tonic is often absent for extended periods of time. This leads to a constantly shifting "root" reference point for harmonized tones, and therefore compromises an attempt at just intonation in an irreconcilable way. In addition, in the author's experience, a scale played in equal temperament will be heard as in tune by most people, even if all notes are sounding at the same time, because the harmony of seven simultaneous tones is significantly complex. However, triads have a more distinguishable and clear quality that lend themselves to more adept listening.

Similarly, a note must be given on the practicality of adjusting perfect fifth intervals: the adjustment for the perfect fifth interval is categorically necessary, as it serves as an equally important part of the interlocking keys that align to make fully just chords. For example, in the major triad, the adjustment for the perfect fifth interval *also satisfies* the adjustment for the minor third interval that occurs between the third of the chord and the fifth. This is part of the beauty of adjustments in this system, as often interior intervals fall into place, so to speak, when the adjustments of the individual tones as they relate to the root are made. However, in reality this perfect fifth adjustment is only two cents (and is actually slightly less than that if the rounded integer is not taken). The human ear is generally known to be incapable of discerning pitch changes less than five cents,[41] and furthermore, it is relatively implicitly obvious to trombone players that micro-adjustments of the slide to that degree are virtually impossible. Even if that degree of technical precision is achievable, it would certainly not be reliable, not even accounting for the nervousness and tremors that often accompany high-pressure musical situations. With the exception of the first one, "Tuba mirum" from Mozart's *Requiem*, shown as an example of the most technically rigorous approach, the adjustment for the perfect fifth will not be included in the analyses. However, as always, the performer should be listening intently for the beatless quality that accompanies all just-intoned intervals.

Included with each analysis is an annotation of the excerpt, discussing the most likely reasons for which the excerpt is "called" at an audition, as deemed by the author and as reasoned from his experience in such settings. In addition, a discussion of any relevant harmonic idiosyncrasies is included.

Realistic Application of Concepts

In a "perfect" world, where all musical sounds are made by machines, or by humans equipped with the type of precision typically reserved for machines, all

41. Carl R. Nave, "Pitch," HyperPhysics, accessed March 21, 2014, http://hyperphysics.phy-astr.gsu.edu/hbase/sound/pitch.html.

harmonies could be justly tuned, no matter how complex, or how quickly they occur. This is because there is, irrefutably, a single frequency arrangement for any given harmonic collection which is mathematically most congruent, and for which the sound waves are the most additive. In this world, one would not worry about the difficulty of making extremely small tuning adjustments, the prohibitively rich amount of knowledge needed by all parties in order to tune every possible chord perfectly, the physical limitations of playing our instruments, or the element of human error. Yet, this is not the world in which we live. The truth is that sometimes "close enough is good enough." Sometimes it is okay, and perhaps necessary, to "meet in the middle" or to "make a judgment call." To pretend otherwise would be, of course, absurd. In fact, the conscientious reader will notice some adjustments in the analyses which could ostensibly be played one of a few different ways; an example is the A3 in "Tuba mirum" which has a suggested "+17," effectively tuning the tritone in inversion. This A3 could also be tuned "−14" to interact with the F4 that follows it, or alternatively the preceding E♭4 could be tuned "−17" to preemptively tune the tritone which is impending. Tricky moments such as these are simply up to the discretion of the performer and his or her judgment, or in the case of this document, the author and his discretion and judgment. And so, at the risk of sounding wholly unscientific, a caveat to the following sections must be made: it may not be possible or entirely practical to achieve intonation that is literally perfect, and sometimes the complexity of the music (such as in a highly contrapuntal passage) renders just intonation both impractical and frankly unnecessary. But whereas playing in tune is best, when playing justly is possible we should try our best to achieve it.

As previously mentioned, occasionally a just-intoned analysis encounters a question for which "meet somewhere in the middle," which will be referred to as a *mediation* from this point onward, may actually be a reasonable answer. This happens most often when a pattern of like intervals is repeated or sequenced, causing each succeeding tone to be farther and farther from an equal-tempered reference point. In fact, this is obviously demonstrated in the shortcomings of the Pythagorean tuning system, which is based on the justly intoned tuning of perfect fifths (and fourths, naturally); certain tones are drastically far from an equal-tempered standard, which "is an awkward result, but is a necessary consequence of the arithmetic."[42] This is an effect that appears multiple times in the analyses of the excerpts, and is what I call the *cascading interval effect.* In the case that a mediation is necessary, these tones will be marked with a minus-sign or plus-sign wrapped in parentheses ("(−)" or "(+)", respectively), indicating a general suggestion to lower or raise the pitch, at the performer's discretion and judgment. Generally speaking though, as the object of the mediation is to be less than the full adjustment, it is recommended that each mediation be considered to be between five and ten cents. The justification for the specific cases of these mediations are given in the individual analyses.

As a final note on the practical application of these concepts, although specific adjustments in cents are given in the analyses, the author encourages the

42. Backus, *Acoustical Foundations,* 120.

reader to become technically proficient at making adjustments in intervals that are roughly five cents wide, which is, albeit difficult, reasonably achievable. Once this skill has been acquired, the exact adjustments given in the analysis can be used as a guideline for how many five cent increments, roughly speaking, the pitch should be adjusted. Again, as ambiguous and unscientific as that may sound, it is perhaps the most approachable method for one to take that will encourage better harmonic performances, without breaking the mental bank, so to speak.

Mitigating Circumstances Arising from Trombone Idiosyncrasies

Before the presentation of these analyses, a few other important considerations and clarifications related to trombone technique should be noted, in order to inform the performer even more deeply. Like most instruments, the trombone itself is subject to idiosyncratic tuning tendencies. Furthermore, these tendencies are not consistent amongst different trombones (even within the same model of the same manufacturer). For example, most trombones play "sharp," to varying degrees, on any notes within the sixth partial of the harmonic series. In addition, while most trombones would naturally play "flat" in the fifth partial of the harmonic series, advancements in trombone manufacturing have overcome this proclivity by manipulating nodal points on the instrument. The result is that, on many modern trombones, the fifth partial begins in first position with a D4 that is sharp, and becomes progressively flat descending from there, usually surpassing the "middle point" by fourth position.

Therefore, it is crucial to understand that the adjustments given are not from any particular slide position on the trombone (like “first position,” “fourth position,” etc.), but from a slide placement that represents notes that are in tune relative to A4=440. Because these placements are variable for the individual and his or her current equipment, the individual must learn the tendencies and idiosyncrasies of that instrument, and practice overcoming them to the point of advanced proficiency. This is a distinct difficulty and therefore an advanced point of knowledge, but for which the technical mastery by the individual is paramount in order to play in tune at all, let alone make conscientious adjustments. Otherwise, any attempt to make intonation adjustments will be made from a tenuous foundation, and likely will not be better than the “luck of the draw,” so to speak.

Finally, there are a variety of other environmental and physiological factors which affect intonation on a constant and ever-changing basis. The current temperature (colder temperatures cause air to travel through the instrument at a slower rate and therefore at a lower pitch), current state of muscular fatigue (this varies amongst trombonists), and changes in instrumental equipment (different instruments and bore sizes, changes of the various aspects of the mouthpiece or leadpipe, and other factors which have dynamic effects on intonation) are amongst the variety of factors present. Certainly, one cannot practically account for all of them simultaneously, so suffice it to say that the trombonist should always tune to a reference pitch (preferably a fundamentally in-tune one such as B♭3) before an audition, and even more preferably as close in temporal and physical proximity as possible to the first notes of the audition.

CHAPTER 7: ANALYSES OF TEN OFT-REQUESTED TROMBONE EXCERPTS

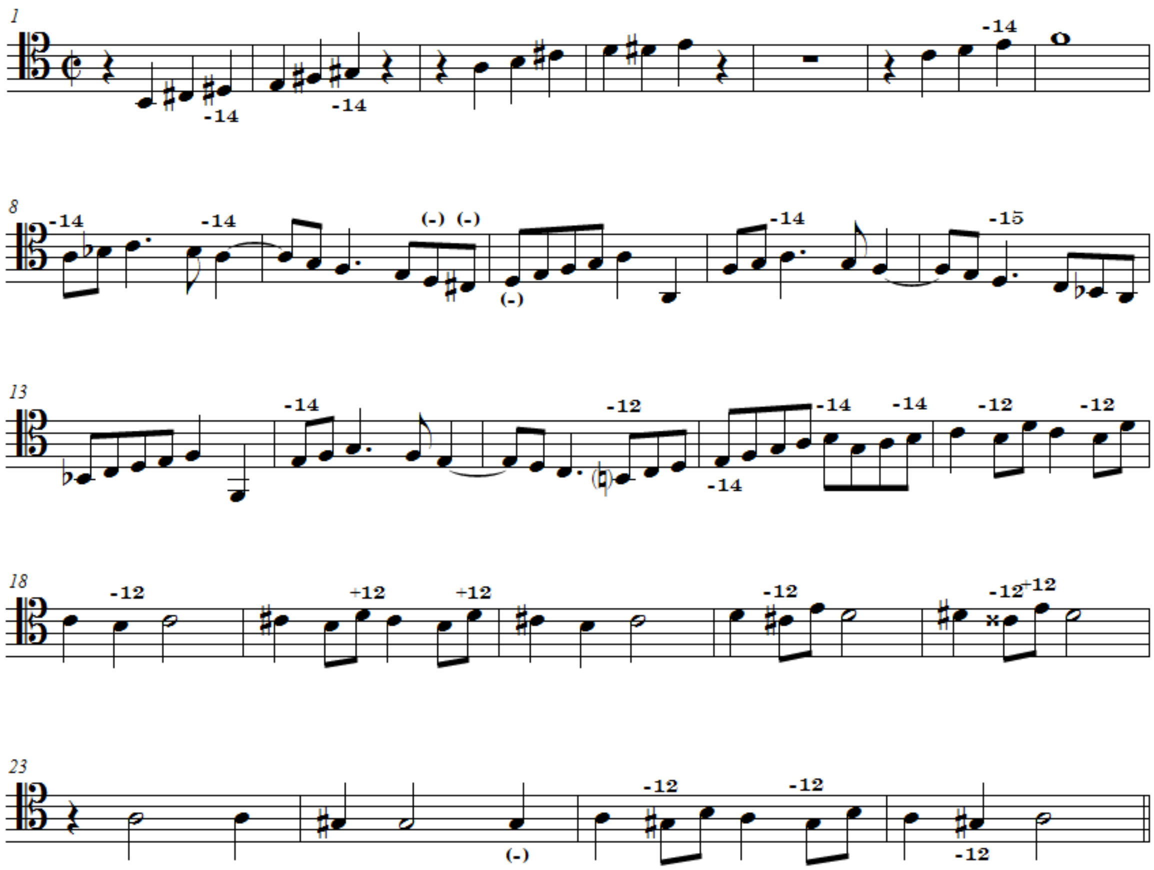
Hector Berlioz: "Hungarian March" from *The Damnation of Faust*

This excerpt (Figure 1) comes from the march which occurs in the third scene of Berlioz's dramatic legend entitled *The Damnation of Faust*. The march gained so much popularity that it is most often performed as a concert piece divorced from its original context. This excerpt, a very commonly requested one, is a full section excerpt primarily in unison and octaves with the other trombones and tuba, although it usually appears in the solo rounds of orchestral auditions (and often in the preliminary, live or recorded, round). Given in the analysis is the second trombone part, which is most often chosen for an audition because of its inclusion of two elements from the bass trombone part: the octave leaps from A3-A2 and F3-F2, and the rising scalar material that precedes the main statement of the excerpt. This excerpt is commonly requested in order for the candidate to demonstrate control, clarity, and consistency of tone and articulation at high volumes and intensity.

This passage has some interesting features related to tuning in a just context. Most notably, the primary melodic statement of this excerpt, a rising and falling syncopated line thrice repeated that outlines third intervals, causes some issues with triadic confusion. In the first two of these statements, there are two triads which are outlined, sharing two common tones each (in the first line, for example, F-A-C first, and then D-F-A later). This presents a challenge in intonation adjustments because, naturally, the two triads are not harmonically compatible, and the tones would undergo different tuning adjustments depending on the root tone. Although they can be combined to form a seventh chord, there are two problems with this alternative interpretation: 1) the “root” of that proposed seventh chord appears last and it is not held out like the other tones, and 2) the first tone of the first statement (A3) is adjacent to a tone that determines its tuning (F4). For this reason, it is advisable to attempt to mediate the tuning in this situation, by tuning the first A3 as a major third, and lowering the D3 at the bottom of the line by an undetermined but noticeable amount. This ensures that the A3 is in tune with the F4 that precedes it, and also accounts for the tuning between D3 and F3 to some degree (allowing the F3 to be raised from equal temperament, as it should be as a minor third), but without adjusting the F3 prematurely before the D3 actually occurs. In the analysis of this excerpt, the D3 and C□3 that follows it are marked plainly with a “(−)” to indicate that the performer should lower the pitch slightly in order to mediate this harmonic situation.

Johannes Brahms: *Symphony No. 1, Fourth Movement*

Although appearing commonly on lists for a final round to be played with other members of the trombone section, this excerpt is often requested in the solo round of a principal trombone audition as well. The soft and delicate entrance in the upper register requires a high degree of air and embouchure control, and the conservative orchestration of Brahms’s symphonies calls for a certain finesse and stylistic

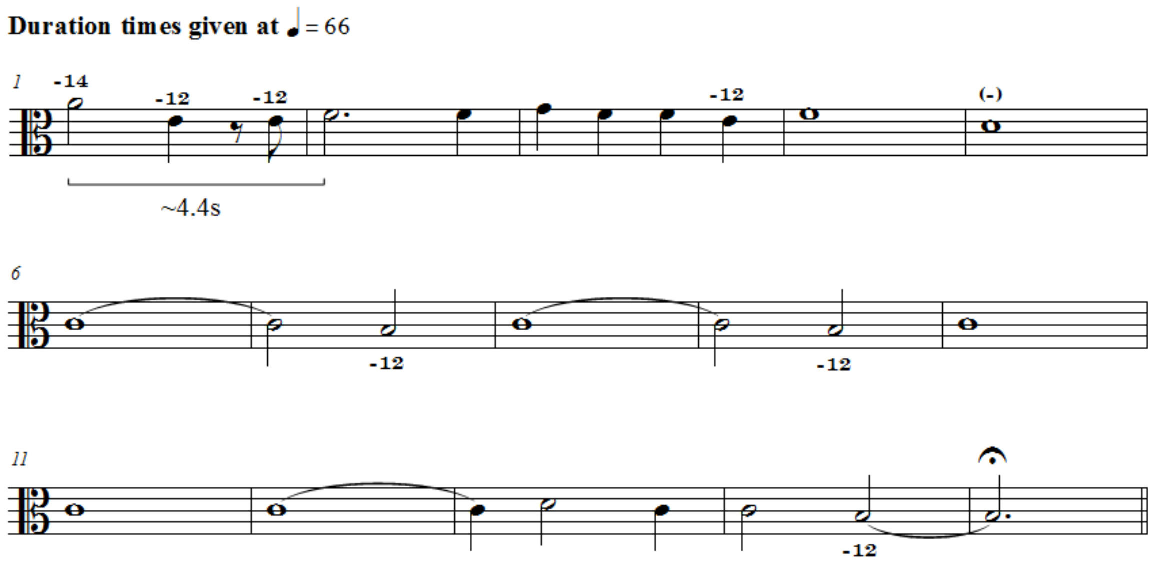
Musical Example 1 – Second Trombone;
Hector Berlioz: "Hungarian March" from *The Damnation of Faust*

sensitivity that tends to expose less advanced players in this excerpt. In addition, although not an issue within an orchestral audition, of course, this passage appears in a symphony during which the trombonists do not play until this final movement, and has only seven total notes preceding it; this treacherous circumstance for the brass musician has led, at least in part, to the fame of this excerpt. The context of this musical moment is a solemn chorale texture, and the trombones are, for the first several bars, accompanied only by the bassoons for color.

This excerpt serves as a fine example of how the underlying harmony will not suffice to dictate the tuning adjustments made in a solo performance (they are however, admittedly, rather close). This is partly due to the fact that the leading tone, when played in harmony with a tonic tone (a minor second interval), is lowered by twelve cents in order to achieve a just interval, while when played in harmony with a dominant tone (a major third interval) it is lowered fourteen cents. Also complicating matters for this excerpt is the fact that, like many other examples, the tonic tone does not appear for quite some time. Finally, the excerpt opens with a perfect fourth, an interval that is easily identified and judged in terms of tuning. Therefore, in this analysis, it is recommended to begin the excerpt on an A4 which is fourteen cents lower than 440 Hz. Conquently, the E4 that follows may be tuned at twelve cents below equal placement, which aligns it with both the A4 and the F4 which is upcoming. These adjustments are as if, at this time, the music is operating in the tonal area of F major, while in reality the full orchestration calls for completed A major, D minor, Eb major, B♭ major, C major, and F major triads. This progression could certainly be seen as (and in fact is) a harmonically complex chorale in the key of F major, however the tuning placements are much different with the chords present than they are as a solo rendition with reverberating harmonies. One of the problems with this analysis is the minor third interval between F4 and D4 in between measures four and five; the D4 is adjacent to both the F4 and the succeeding C4, and unfortunately those two intervals are not harmonically compatible. For the minor third to be in tune, the F4 would need to be sixteen cents raised, while for the major second to be in tune, the D4 would need to be four cents raised. Were the F4 raised, the leading tone interval preceding it would be drastically compromised. Should the D4 be raised instead, the minor third interval would be even worse. Finally, if the D4 were fully lowered to create an inversely tuned interval, the major second to the C4 would be either quite out of tune, or the C4 would need to be pushed down twenty cents past the equal-tempered tuning of a middle C. Therefore, another mediation is in order here, and by lowering the D4 just slightly, the minor third is not egregiously wrong and neither is the major second, while the leading tone E4-F4 is left still intact. The remainder of the excerpt is easily handled, with the B3-C4 leading tone the only concern.

Gustav Mahler: *Symphony No. 3, First Movement*

The trombone solo excerpt from the first movement of Mahler's *Symphony No. 3* is often referred to as the most extensive solo in the orchestral trombone literature. This movement features three different lengthy solos (the first and third being very similar), and the first one is given an analysis here due to its significantly higher frequency of appearance on audition lists. Melodically, the excerpt gravitates toward an A3 pitch, while harmonically the excerpt seems to struggle, or perhaps toy, with varying presences of the D major and minor modes. This of course befits the polarity posited by the entirety of the symphony, which begins in D minor but ends in D major. In regards to orchestration, the principal trombonist plays this excerpt primarily solo, accompanied by rhythmic string accents quoting a principal motif of the movement, as well as chordal support from the remaining wind instruments. The remainder of the low brass section does enter to enhance the trombone solo a bit later on, reinforcing certain critical parts of the melody in

Musical Example 2 – First Trombone;
Johannes Brahms: *Symphony No. 1, Fourth Movement*

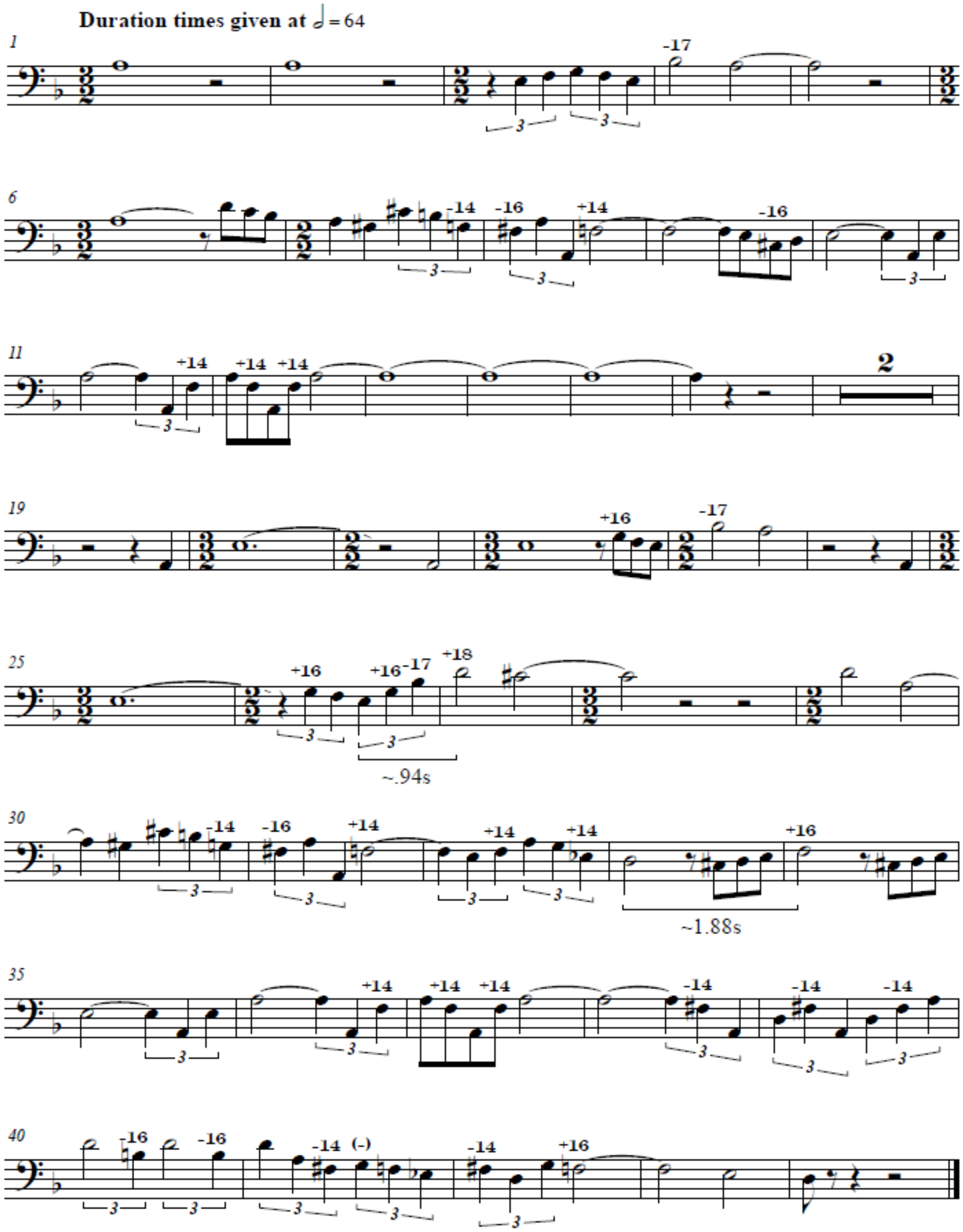


unison, until finally playing in emphatic harmony for the final five measures of the excerpt. This excerpt is requested for a wide variety of reasons, including interpretational, phrasing, and breathing challenges, as well as to give the performer an opportunity to showcase his or her ability to project the powerfully ominous presence that characteristically defines the instrument.

Tuning in this excerpt is not challenging per se, but does present a variety of interesting interactions. Most obviously, there are a fair amount of inversely tuned intervals. This is due to the fact that the note A3 is extremely prominent in the excerpt, and serves as a sort of gravitational center, and therefore it is suggested to avoid playing different tunings of this note. This causes several iterations of an F3 to be tuned inversely, which unfortunately includes the additional complication of being a raised tone in first position. Another instance of a raised first position note occurs in measure twenty-seven, as the D4 must be raised to complete a just tuning of a prominently arpeggiated half-diminished chord. In addition, in measure thirty-two the Eb3 is inversely tuned, which is mostly because of its order of appearance but also has the added benefit of coming close to creating a just-intoned minor second with the D3 that it follows. Finally, in the antepenultimate measure there is no way to reconcile the trio of notes that is Eb3-F□3-D3, as one of the intervals will necessarily need to be sacrificed. The major third tuning of the F□4 was chosen because of the general centeredness of the excerpt around D, as well as the fact that another F□3 appears in close proximity with that tuning.

Wolfgang Amadeus Mozart: "Tuba mirum" from *Requiem*

This excerpt appears at the very beginning of the "Tuba mirum" movement of Mozart's *Requiem,* and is one of the most commonly requested and widely known trombone excerpts in the orchestral literature. The excerpt prominently features a solo trombonist, who begins the movement entirely solo (an extremely rare occurrence) and is soon joined by the baritone voice soloist. Originally, this excerpt was written for the tenor trombone in a trombone section that consisted of one of each type of orchestral trombone (alto, tenor, and bass). Today, regardless of whether the section chooses to perform the excerpt with this period instrumentation or with modern instrumentation (which would include a tenor trombone in the principal part), the second trombonist will perform the solo. It is, however, equally requested for principal trombone auditions as it is for second trombone auditions. Besides the obvious notoriety and prominence, this excerpt is

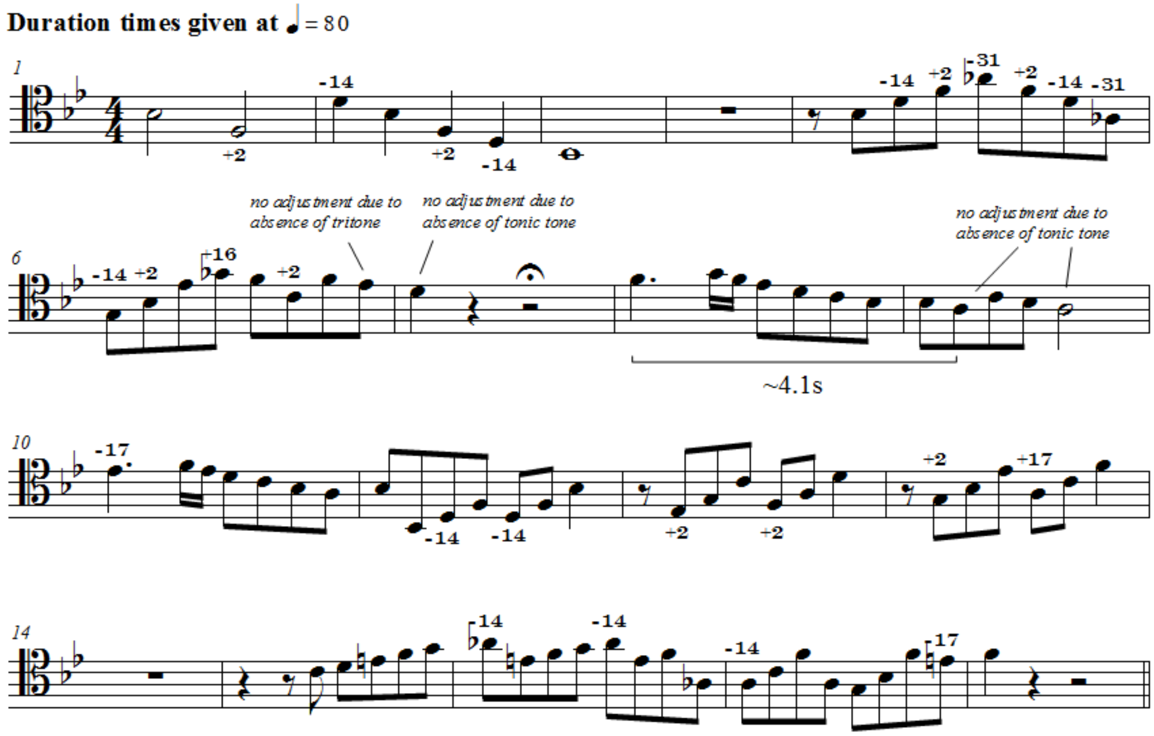
Musical Example 3 – First Trombone;
Gustav Mahler: *Symphony No. 3, First Movement*

requested in order for the committee to listen for stylistic interpretation and technical fluidity, phrasing, tempo control (including rest-counting), and intonation.

With relation to the intonation adjustments, this excerpt contains several triadic statements and one very prominent dominant-seventh chord outline. In most situations, these notes will be played in close enough proximity to necessitate the adjustment of all tones of the dominant-seventh chord. The most notable point of harmonic ambiguity is the sequence of ascending triads in first-inversion, which also serves as the first example of the discrepancy between played harmony and functional harmony. Although the just system would have each minor third raised by sixteen cents in order to create a just interval with the root tone, due to the inversion, the root tones of the triad are adjacent to the minor third of the succeeding triad. Therefore the interval present in the reverberated harmony is a perfect fifth, and the interaction between the minor third and its functional root is less present and takes a lower priority. Finally, near the end of the excerpt, an A♭ is played in close proximity to an E, making the enharmonic interval of a major third, twice. However, the F that occurs before the A♭ and after the E renders the passage as solidly sounding in the key of F minor, and therefore the appropriate adjustments thereof apply.

Nicolai Rimsky-Korsakov: *Russian Easter Overture*

This excerpt, which states a liturgical theme from the Russian Orthodox chant collection called the *Obikhod,* begins at Rehearsal M and ends at Rehearsal N

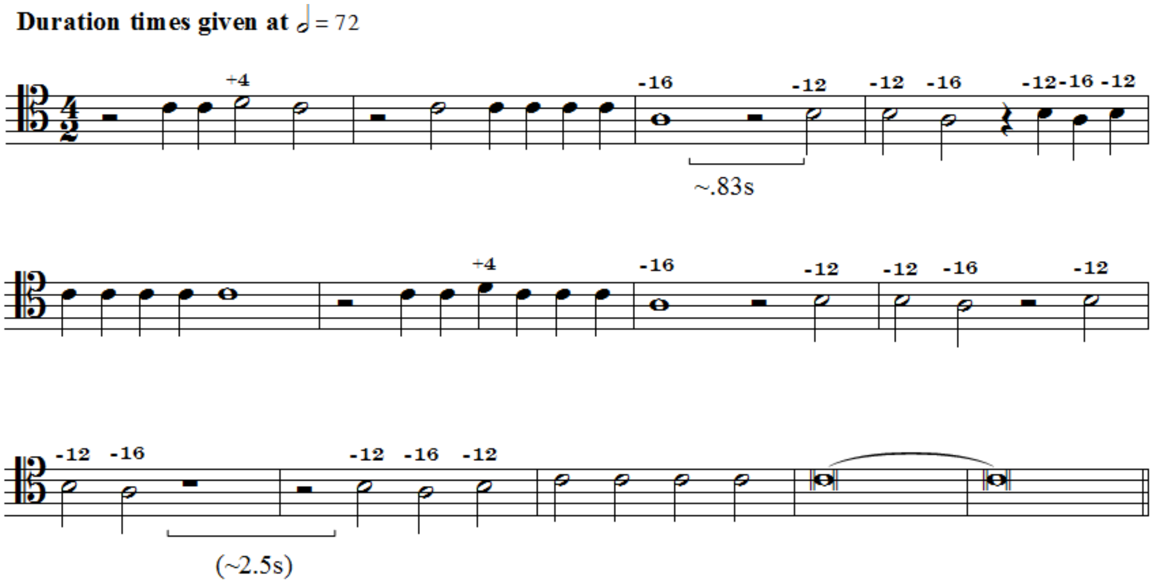
Musical Example 4 – Second Trombone;
Wolfgang Amadeus Mozart: "Tuba mirum" from *Requiem*



(in most editions). The part is marked *a piena voce*, or "in full voice," and prominently features the trombone soloist. The solo is accompanied only by a sustained chordal string background (with the exception of the violin solo that begins on the final note), and it is commonly understood that this passage, with its emphatic, declamatory nature and modally melodic character, is meant to evoke the voice of a priest at an Easter ceremony. The passage is best performed with subtle expression and graceful phrasing, as well as a projected and present but warm tonal character, and is commonly asked at auditions for these reasons.

The tuning of this passage is rather interesting and presents a common problem with the application of just intonation in a solo passage, as well as another demonstration of how the performance in an audition setting would differ from the performance with a live orchestra. Although the excerpt is firmly rooted within a minor tetrachord spanning from A3 to D4, the first A3 does not appear until well after the C4 has been established. In a live setting, this opening C4 would be adjusted appropriately for its place in the A-minor triad that accompanies it (raised sixteen cents), however, in a solo setting it is suggested that the performer invert the adjustment, such that the A3 is lowered sixteen cents (which still allows for a minor third interval that is exactly 316 cents apart, the correct spacing for a minor third). This also allows for the major second interval between the C4 and the D4 which opens the excerpt, as well as the A3 and B4 that is often repeated, to be played with proper spacing (204 cents apart). While the sacrifice here is that the interval between the A3 and the D4 is not just (520 cents instead of 498 cents), these tones are not likely to sound harmoniously in this excerpt. One might suggest that the first C4 played should simply be played sixteen cents sharp to begin with, however, with no other context in a solo round, the D4 that follows would then require a tuning of "+20," which is both the farthest removed from equal temperament as well as requiring an alternate position that is generally less desirable for the trombonist. As previously mentioned, a performance with a symphony orchestra would negate these adjustments, with A minor, D major, and D minor harmonies taking precedence and requiring alternate placements.

Musical Example 5 – Second Trombone;
Nicolai Rimsky-Korsakov: *Russian Easter Overture*

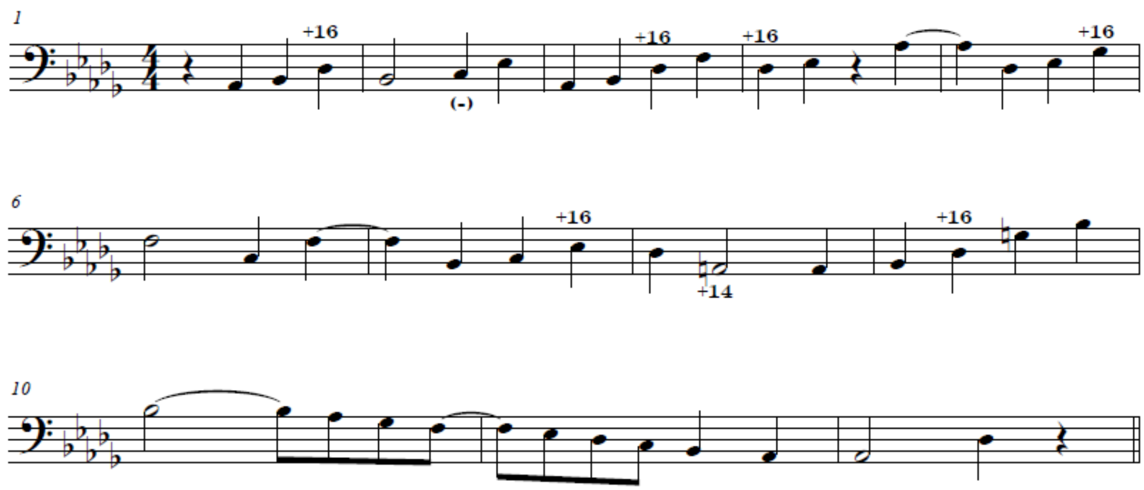
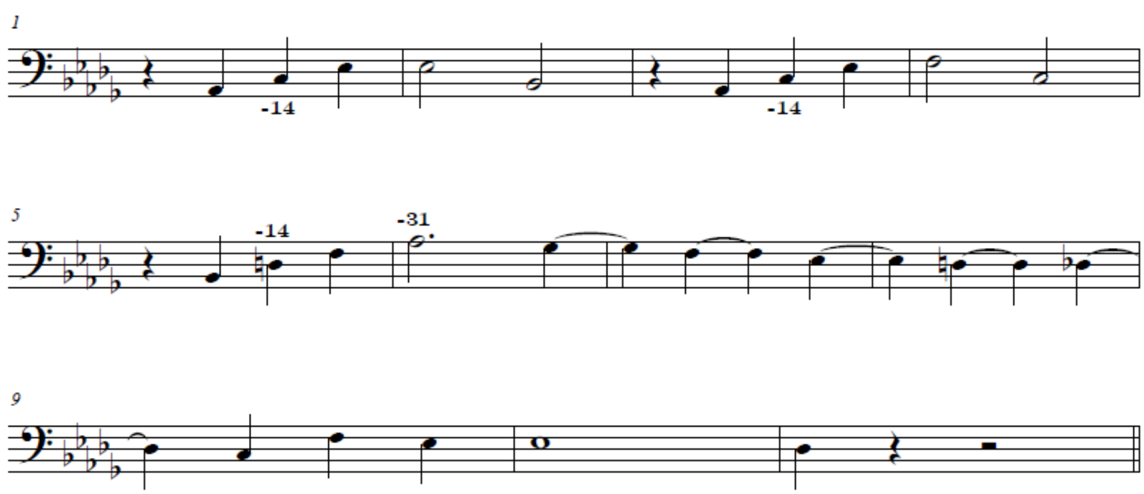


Camille Saint-Saëns: *Symphony No. 3 "Organ", First Movement*

This moment from Saint-Saëns's "Organ" symphony is one that truly exposes the principal trombonist. Played solo as a trio with clarinet and horn two octaves apart, this beautiful theme is played at a soft volume and quite slowly. There are two excerpts which actually present a single melody completely, preceded and separated by identical melodic statements by the strings. In a solo audition setting, the excerpt should be played at a speed which favors the breathing limitations of the performer, with respect to proper phrasing. In addition, several alternate positions exist that facilitate a well-played *legato* style, but which tend to exacerbate margin of error in both tone and intonation. The excerpt, when played at its highest degrees of competency, highlights tenderness, sensitivity, and a melodic beauty that is oft absent from orchestral trombone writing. Intonation is of course of paramount importance in a live performance with full orchestra, due to the doubling with clarinet, a pure-toned instrument with which tuning conflicts are rather obvious.

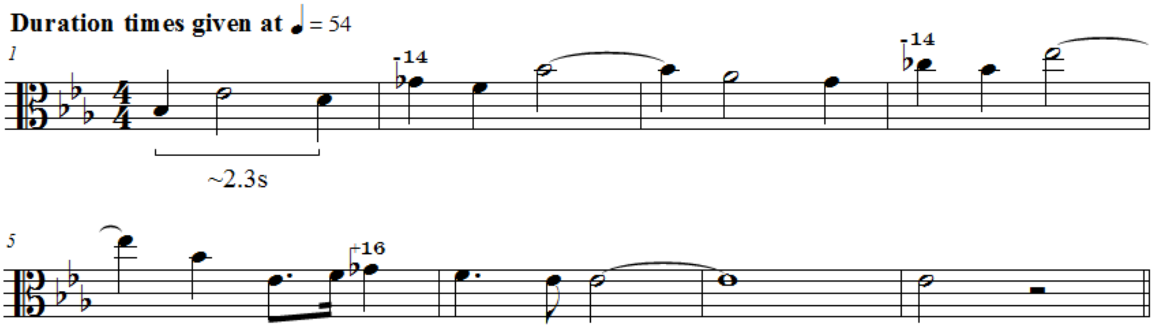
While the second excerpt involves only a few simple triadic adjustments, the first is more interesting. In measure two, and unlike several other instances in this excerpt, a mediation of the C3 is appropriate (lowered slightly) in order to approximate the minor third interval upcoming. This is because if the Eb3 were raised sixteen cents to create a justly tuned minor third interval with the C3, the perfect fourth interval that follows would be noticeably out of tune (and as has been consistent with these analyses, perfect intervals take precedence over non-perfect intervals). In measure eight, the augmented fourth interval is inversely tuned, in order to avoid a whole step interval between Eb3 and D□3 that is twenty-six cents too wide (a lowered D□3, instead of a raised A2, would result in a whole step distance of 330 cents, as opposed to 304 cents in just tuning). Finally, in the following measure, an interesting and convenient phenomenon occurs by making only a single adjustment in this measure, a sixteen cent raising of the D□3; while the appropriate tuning for a diminished triad is absent, and the minor third interval between G3 and B□3 is sacrificed, the tritone and B□-D□ minor third interval are intact. This allows the sustained B□3 to be played with equal temperament, avoiding a potential cascading interval effect with the upcoming scale.

Musical Example 6 – First Trombone;
Camille Saint-Saëns: *Symphony No. 3 "Organ", First Movement*

Excerpt 1

Excerpt 2

Robert Schumann: *Symphony No. 3, Fourth Movement*

This excerpt is a treacherous one for trombonists for a variety of reasons, only one of which is the extended range required. In addition, the excerpt contains the first notes played by the trombone section in the symphony, but does not appear until the fourth of five movements. Finally, the entrance of the chorale, and almost all of the remainder of it, is at a very soft dynamic and is accompanied sparsely (by only horns, bassoons, and string pizzicati). Although the excerpt appears commonly in the section round of an audition (and is subject to different tuning adjustments, which are appropriate for the actual vertical harmonies of this passage), it is occasionally requested in the solo round of an audition as well. The audition committee chooses this excerpt simply to hear the range limitations of the trombonist, and so performing the E□5 with a professional tone quality is paramount. In addition, tempo control and delicacy of phrasing is secondarily important.

There are only a few tuning adjustments which should be made during a solo performance in a reverberant setting, but they are perhaps not intuitive, which is the reason that this excerpt is included. While the D4 is likely to be sufficiently separated from the opening B□3 to avoid the necessity of an adjustment, the diminished fourth interval that follows should be lowered by fourteen cents. Similarly, the diminished fourth interval of measure four receives the same treatment. Third and finally, although scalar adjustments have been primarily avoided in these analyses, the G□4 in measure five should be adjusted for the minor third interval it creates with the E□4 that precedes it, due to the transient nature of the scalar passing tone and close proximity that it creates.

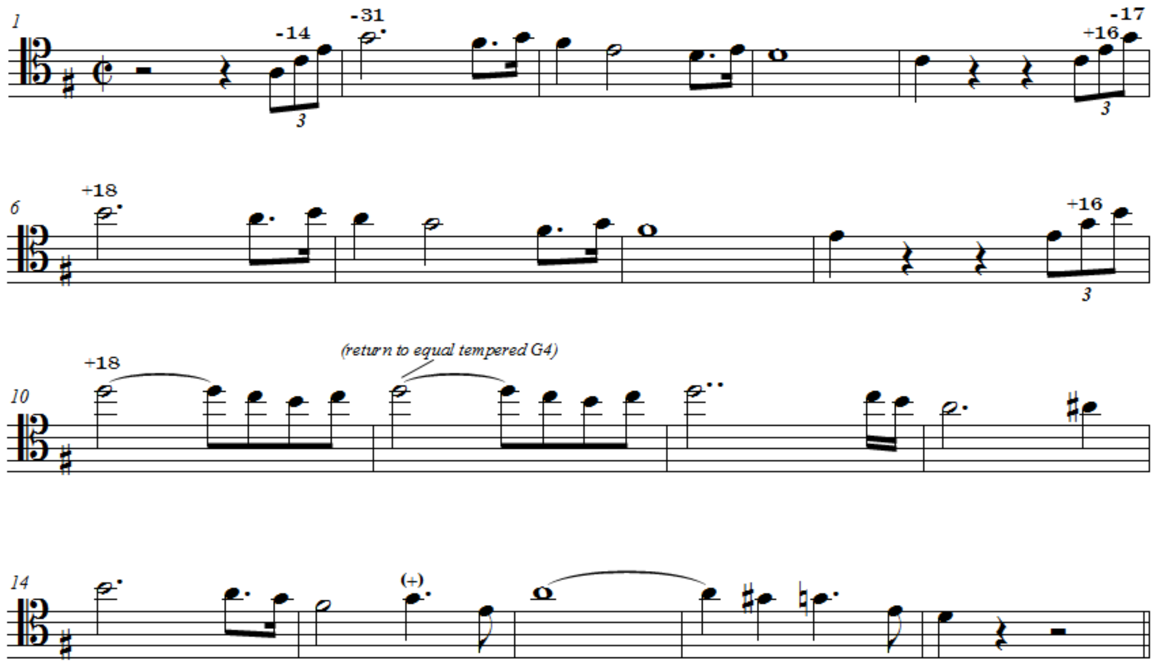
Musical Example 7 – First Trombone;
Robert Schumann: *Symphony No. 3, Fourth Movement*

Richard Wagner: "Prelude to Act III" of *Lohengrin*

This excerpt, the most famous of two from Wagner's *Lohengrin*, appears in the prelude to the third act of the opera. The excerpt occurs twice in the prelude, with the only difference in the principal trombone part being either a short G3 or sustained B3 for the final tone (this analysis gives the first rendition). In the author's experience, when this excerpt is requested in solo rounds, the first appearance is most often requested, likely for the fact that this playing is harmonically self-contained. The excerpt features the trombone and tuba playing in unison, although the tuba drops out for nearly four bars mid-excerpt, while the second rendition has the bass trombone and tuba in a lower octave harmony (and the tuba this time plays throughout). Audition committees request this excerpt likely for its technical difficulty at high volumes, as well as to listen for the player's ability to sustain broadly for an extended period of time.

Tuning in this excerpt is relatively straightforward, if one ignores the major and minor second adjustments (as suggested earlier). Three seventh chords of unique quality are featured at a high speed and volume, calling for appropriate chordal adjustments. This nature renders the excerpt a fine candidate for the teaching of the basic tuning concepts of seventh chords, as three of the four most common (the "dominant", "minor-minor," and "half-diminished") seventh chords are used (excepting the "fully diminished" seventh chord). There are two interesting complications in this excerpt: the G4 that is played in the tenth bar of the excerpt is adjusted for its place in the "minor-minor" seventh chord, however, it is required to return to equal temperament for the impending perfect fourth interval with D4 that it will soon create (or risk a necessity to adjust the D4 rather sharp as well, leading to another cascading interval effect). The other interesting factor of note is the C4 in the fourth-to-last measure of the excerpt: here it is recommended to slightly raise the tone. In this way, the minor third interval that follows (+16) as well as the minor second interval that precedes (+12) are at least partially achieved. However, the C4 in the penultimate bar is left alone, despite having a similar succeeding tone, due to the importance of maintaining the integrity of the perfect fourth interval between C4 and G3, which are played in close succession.

Richard Wagner: "Overture" to *Tannhauser*

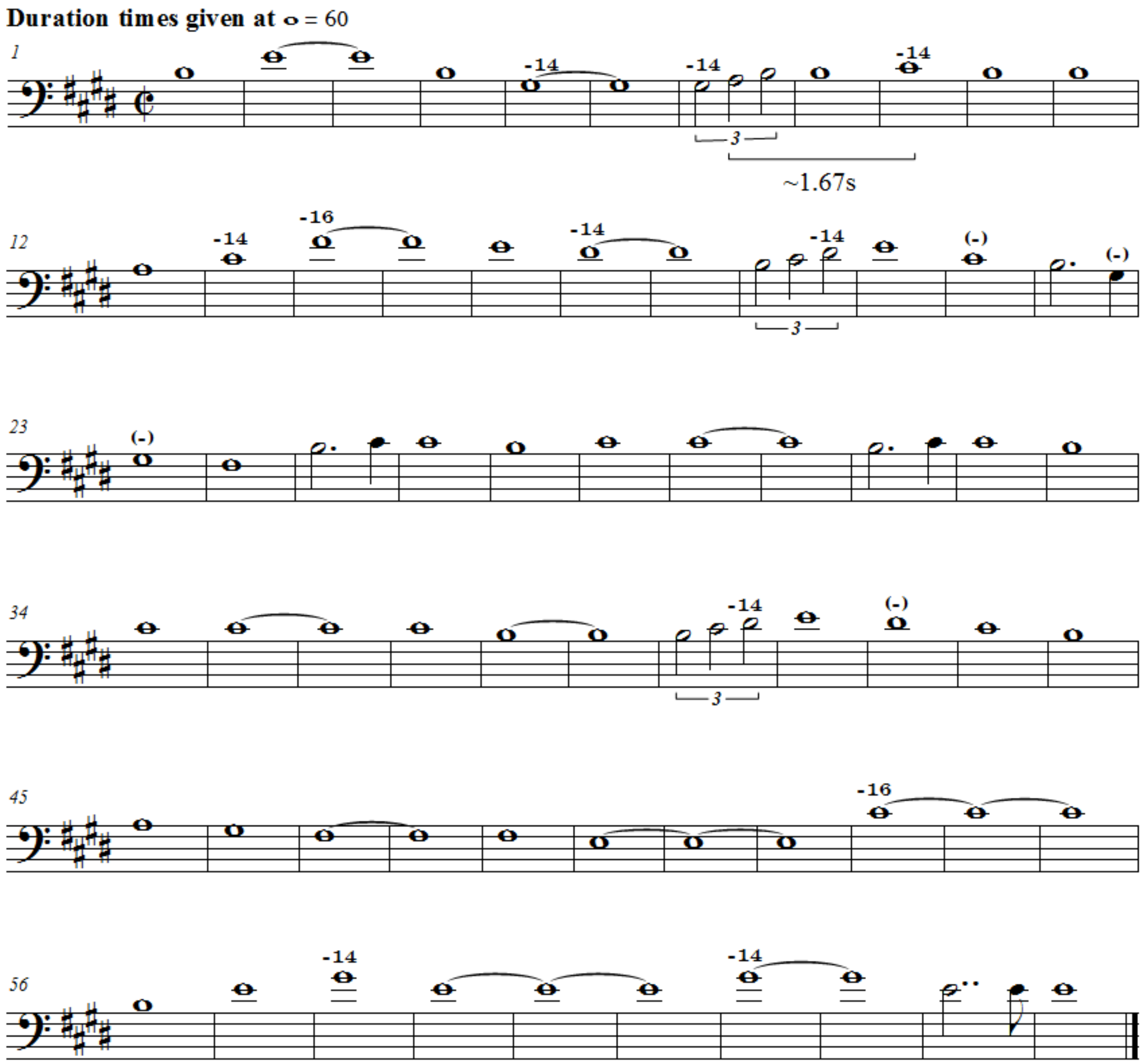
Excerpted from the famous "Overture" to *Tannhauser*, this excerpt also appears twice with some variation. Given in this analysis is the final playing of this notable theme, which was chosen for its extended and triadic ending. Like many

Musical Example 8 – First Trombone;
Richard Wagner: "Prelude to Act III" of *Lohengrin*

Wagner excerpts, this excerpt is often chosen to give the auditioning trombonist an opportunity to showcase his or her ability to play powerfully with an excellent tone and intonation. In addition, as with many unison or octave "section excerpts," the performer is required to play with great control and consistency, as would be required to achieve a homogeneous and world-class section sound. Finally, breathing in this excerpt can be challenging, due to the well-sustained and symmetrical phrases that beg to be uninterrupted.

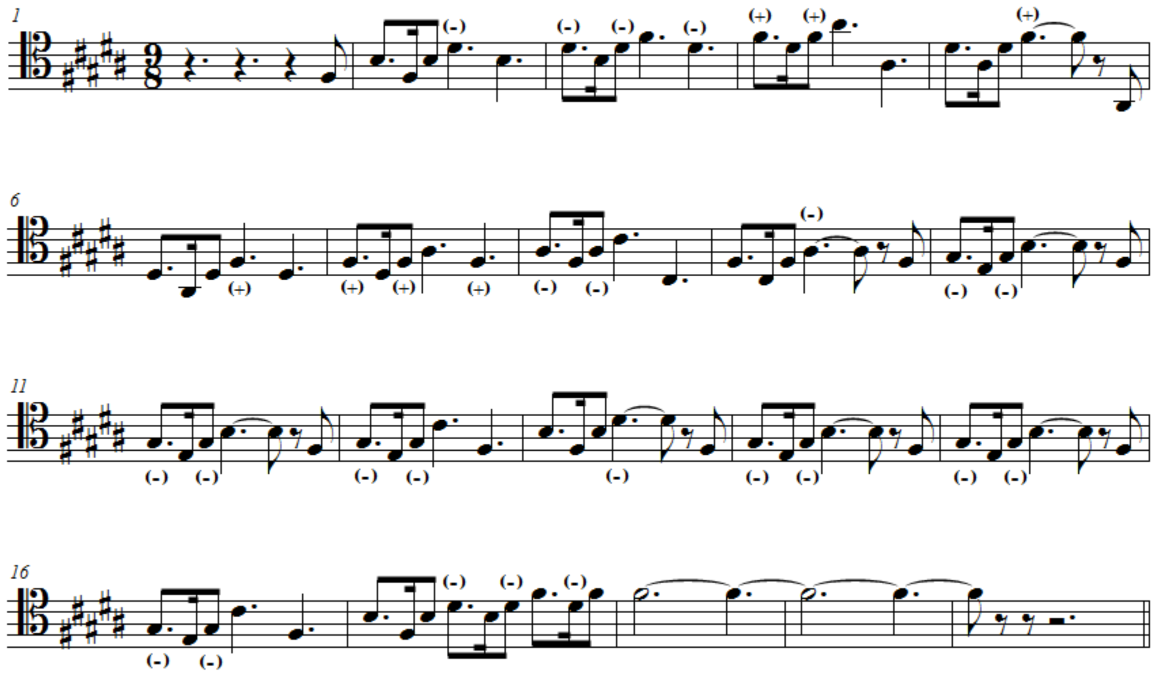
This excerpt features primarily obvious tuning adjustments, but has a few moments of note. The first is a lowered C□4 in measure nine, which despite seeming sufficiently distant from the preceding A3 visually, is temporally rather close, due to the tempo of this excerpt. Second, an F□ minor triad is necessarily inversely tuned, due to the order in which the tones are introduced. This leads to a complication with the D□4 that follows a few measures later, as the D□4-F□4 interval should be 316 cents apart in just tuning. Without adjusting the D□4, this interval would only be 284 cents apart. However, by lowering the D□4 by fourteen cents, a mediation of this problem is achieved (298 cents intervallic distance, nearly equal-tempered) alongside an appropriate anticipation of the B3 that follows immediately afterward. In addition, some mediations are given, such as the C□4 in measure twenty-one and the G□4 in measure twenty-two, which are both lowered to approximate a just minor third interval, inversely tuned, without significantly compromising the upcoming major second interval.

Richard Wagner: "Ride of the Valkyries" from *Die Walküre*

Perhaps the most publicly well-known trombone excerpt (an accolade that should probably be credited to Bugs Bunny), this part is from the third act of the second opera in Wagner's *Der Ring des Nibelungen* opera cycle. This prelude and scene is often performed as a stand-alone instrumental concert-piece, and prominently features the entire brass section. Although the trombone parts are rich with excerpt-able material, the most commonly requested excerpts are the "major" or "minor" statements of the primary theme. The major statement occurs twice in its entirety for the tenor trombones, with the melodic differences being only the final tone (a short unison B3 or a sustained B-major triad) and the octave placement of

Musical Example 9 – First Trombone;
Richard Wagner: "Overture" to *Tannhauser*

the excerpt's fifth full measure in the principal trombone part. The excerpt is requested so that the candidate can demonstrate control of tone and articulation at high volumes and with wide intervals, as well as for the oft-neglected integrity of the dotted rhythm that is perpetuated.

This excerpt features some of the most pronounced tuning challenges yet encountered. The passage is almost exclusively triadic and very loud, a condition toward which this thesis is perhaps most catered; in this scenario, a performance in equal temperament has a high probability of being recognized as out of tune. Unfortunately it is also, in the author's opinion, one of the most difficult to tune justly. The triads consistently pivot around common tones that receive different tuning adjustments in their respective functional harmonies; for example, the third of the previous chord becoming the fifth of the next. The result is that, if true just intonation adjustments were made, notes of the same type would be tuned differently in close proximity. This is highly undesirable as unison harmonies are some of the easiest to hear as out of tune, which would defeat the purpose of attempting to make adjustments that improve intonation. An alternative option would be to simply adjust the neighboring tones as well by playing the entire excerpt using a just-intoned B major scale. Although this approach avoids the discrepancy between unison harmonies, it leads to two issues that are less than ideal: 1) the excerpt would then contain a great many adjustments, perhaps more than are practical, and 2) six instances of major second intervals (F□–G□) and, more importantly, two instances of perfect fourth intervals (G□–C□) would be twenty-two cents removed from an equal tempered placements. Due to this large discrepancy in frequency, and the priority given to perfect intervals, performing the excerpt entirely justly in B major is not recommended. Therefore, both equal-tempered and true just-intoned options are not ideal, and adjustments of around five to ten cents are likely to be a decent compromise. For this reason, all adjustments given in the analysis of this excerpt are mediations. It is suggested, however, that the performer attempt to be as consistent as possible with the "size" of the mediation (in cents), as consistency is highly conducive to aural acceptance (as proven by the equal-tempered trickery that plagues unsuspecting organists).

Musical Example 10 – First Trombone;
Richard Wagner: “Ride of the Valkyries” from *Die Walküre*

CHAPTER 8: CONCLUSION

It is obvious, given anecdotal and physical evidence, that harmonies resulting from reverberation in live auditions are noticeable, interactive, and have an effect on the overall quality of the audition. This is a critical problem to solve, or at least attempt to mitigate, given the high priority assigned to quality of intonation throughout an audition. By understanding the basics of the tuning systems of equal and just temperaments, as well as by having awareness of the amount of reverberation present in the room in which the trombonist is performing, one can take steps to substantially improve the quality of the audition in this regard. Perfection is of course entirely unachievable, as the situation is complicated by the presence of multiple variables; these include technical error, nervousness, room temperature, instrumental idiosyncrasies, and erroneous judgments made by the audition committee. However, when dealing with such an important area of the audition, and as the audition is in many cases the only true “job interview” for the professional orchestral performer, it is wise to eliminate the variable of reverberant acoustic settings. Fortunately for the musician, this requires only the knowledge posited by this document, and a little bit more practice.

APPENDIX A: ESTIMATED DECIBEL LEVELS OF COMMON SOUNDS

dB level	**Sound**
0	Weakest sound audible
10	Breathing
20	Rustling leaves
30	Quiet rural area
40	Background noise, ambient sound
50	Conversation at home, moderate rainfall
55	Microwave oven
60	Conversation at restaurant
70	Vacuum cleaner, freeway noise from 50ft away
80	Food blender, garbage disposal
85	Smoke alarm
90	Train whistle from 500ft away
95	Jackhammer from 50ft away
100	Motorcycle, full orchestra at *fortissimo*
110	Car horns
115	Loud rock concert
120	Chain saw
130	Hydraulic press
140	Aircraft carrier deck, fireworks
150	Jet take-off
165	12-guage shotgun blast
180	Destruction of hearing tissue

Sources:

http://www.industrialnoisecontrol.com/comparative-noise-examples.htm

http://www.audiology.org/practice/resources/PublishingImages/NoiseChart85x11.pdf

http://www.gcaudio.com/resources/howtos/loudness.html

http://www.hearnet.com/at_risk/risk_trivia.shtml

APPENDIX B: CALCULATOR FOR DETERMINING TUNING SYSTEM

“Back end” design shown for replication if desired.

	A	B
1	**To create this calculator in Excel, simply copy the formulas (only) below.**	
2	**(be sure to use exact same cells shown here, or otherwise change references as appropriate)**	
3		
4	**Reverberation Calculator**	
5	*Time in between notes (seconds)*	**=B13**
6	*Volume played (dB)*	**88**
7	*Reverberation Time of Room (seconds)*	**2.2**
8	*Current level of reverberated tone*	**=B6-(B5/B7*60)**
9		
10	**TIBN Calculator (optional)**	
11	*Performance tempo*	**96**
12	*Total beats between notes*	**2.5**
13	*Time in between notes*	**=B12/(B11/60)**
14		
15	**Equal or Just?**	**=IF(B8<40, "Equal Temperament", "Just Intonation")**

“Front end” results.

	A	B	C
1	**Reverberation Calculator**		
2	*Time in between notes (seconds)*	**1.56**	<<< Here, enter the total time in between the notes in question. If unknown, use "TIBN Calculator Below"
3	*Volume played (dB)*	**88**	<<< Here, enter the estimated or observed volume played.
4	*Reverberation Time of Room (seconds)*	**2.2**	<<< Here, enter the estimated or observed reverberation time of the room.
5	*Current level of reverberated tone*	**45.4**	<<< This cell shows the calculated decibel level of the reverberated tone when the new tone is sounded.
6			
7	**TIBN Calculator (optional)**		
8	*Performance tempo*	**96**	<<< Here, enter your performance tempo.
9	*Total beats between notes*	**2.5**	<<< Here, enter the total number of beats (denominator of time signature) in between the notes.
10	*Time in between notes*	**1.56**	<<< This cell shows the time in seconds in between notes, and this number appears in cell B5.
11			
12	**Equal or Just?**	**Just Intonation**	<<< This cell gives an answer, based on the B10 cell.

APPENDIX C: KNOWN REVERBERATION TIMES OF HALLS AND AUDITORIA

RT60	Location
0.00	Outdoors, anechoic chamber
0.40	Average bedroom, living room (carpeted)
0.50	Recording studio
0.80	Average classroom, conference room
0.90	A theater designed for speech
1.00	Average movie theater
1.30	New Glyndebourne Opera House
1.30	Orchestra Hall, Chicago
1.40	Palais Des Beaux-Arts, Brussels
1.50	Royal Festival Hall, London
1.70	Carnegie Hall, New York
1.70	Severance Hall, Cleveland
1.70	Opera House, San Francisco
1.70	Arie Crown Theatre, Chicago
1.80	Symphony Hall, Boston
2.00	Stadt-Casino, Switzerland
2.05	Musikvereinsaal, Vienna
2.10	St. David's Hall, Cardiff
2.10	Concertgebouw, Amsterdam
2.20	Kennedy Center, Washington
2.40	Symphony Hall, Birmingham
2.60	Royal Albert Hall, London
3.50	Grosser Tonhallesaal, Zurich
8.50	Notre Dame Cathedral, Paris
8.76	Astrodome, Houston
13.00	St. Paul's Cathedral London
14.95	Kingdome, Seattle

Sources:

http://hyperphysics.phy-astr.gsu.edu/hbase/acoustic/revlow.html#c1

http://www.fujitsu-ten.com/business/technicaljournal/pdf/5-6E.pdf

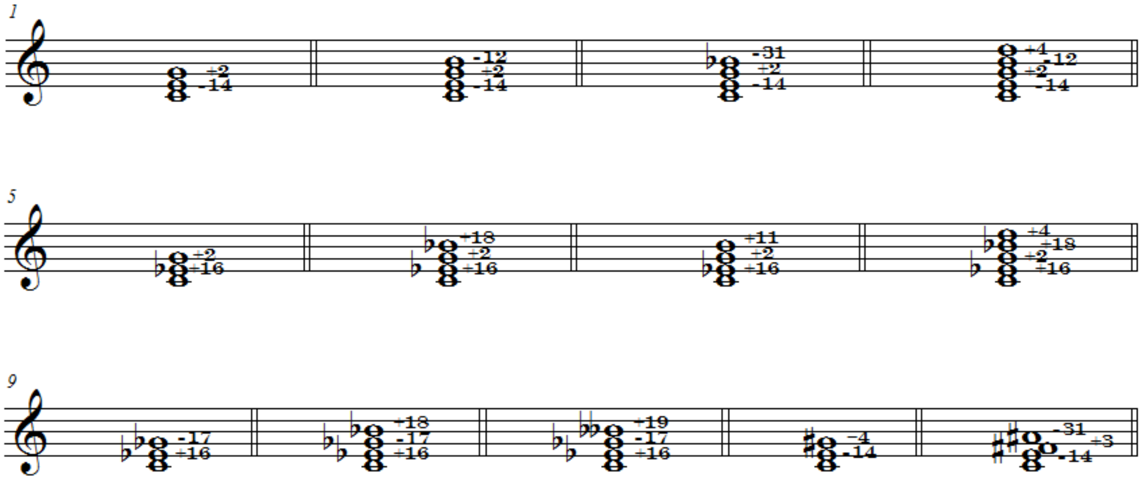
http://www.acoustics.salford.ac.uk/acoustics_info/concert_hall_acoustics/?content=reverb

http://www.acousticalsolutions.com/optimum-reverberation-times

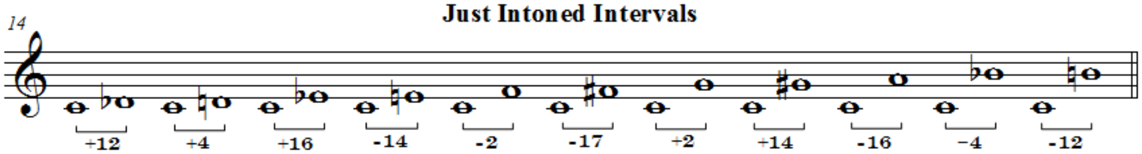
http://www.soundandcommunications.com/archive_site/audio/images/2005_pics/sc05_11_audio02.gif

APPENDIX D: TUNING ADJUSTMENTS OF COMMON CHORDS AND INTERVALS

Just Intoned Common Chords



Just Intoned Intervals



(Number given is the size that the interval needs to "stretch" or "shrink" in order to be in tune. Therefore, given a consistent C4 tone, the upper tone should receive the noted adjustment.)

APPENDIX E: FREQUENCIES OF PITCHES WITHIN TROMBONE RANGE, A4=440

Pitch	Frequency (Hz)	Pitch	Frequency (Hz)
A1	55.00	A3	220.00
B□1	58.27	B□3	233.08
B1	61.74	B3	246.94
C2	65.41	C4	261.63
C□2	69.30	C□4	277.18
D2	73.42	D4	293.66
E□2	77.78	E□4	311.13
E2	82.41	E4	329.63
F2	87.31	F4	349.23
F□2	92.50	F□4	369.99
G2	98.00	G4	392.00
A□2	103.83	A□4	415.30
A2	110.00	A4	440.00
B□2	116.54	B□4	466.16
B2	123.47	B4	493.88
C3	130.81	C5	523.25
C□3	138.59	C□5	554.37
D3	146.83	D5	587.33
E□3	155.56	E□5	622.25
E3	164.81	E5	659.25
F3	174.61	F5	698.46
F□3	185.00	F□5	739.99
G3	196.00	G5	783.99
A□3	207.65	A□5	830.61

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