I, Christina Haan, hereby submit this original work as part of the requirements for the degree of Doctor of Musical Arts in Organ.

It is entitled:
The Emperor and the Pope: the Challenge of Orchestrating For the Organ and the Orchestra

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This work and its defense approved by:

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The Emperor and the Pope:
the Challenge of Combining the Organ and the Orchestra

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Abstract

This paper examines the possible meanings of statements made by Hector Berlioz (1803-1869) and Richard Strauss (1864-1949) in Berlioz’s Grand Traité d’Instrumentation et d’Orchestration modernes about the difficulties of composing for organ and orchestra, and their advice on how to solve these difficulties. (Strauss later published this treatise with his own comments interpolated.) Although most orchestral instruments and organs Berlioz could have heard have changed in design since his day, our team—a musician, an engineer, and an engineer-musician—searched present day combinations for the possible existence of the difficulties described. Recordings were made of Principal and Reed stops on three organs built by different companies and installed in different acoustics. The harmonic frequencies of these stops were compared with those of four selected orchestral instruments—violin, flute, oboe, and horn—to determine if there is a fundamental inability to tune with the organ. Our team concluded that flutes and oboes can make instantaneous adjustments and tune perfectly with the organ, but violins and horns produce much dissonance. Berlioz’s Te Deum, Op. 22, Strauss’s Also sprach Zarathustra, Op. 30, Saint-Saëns’s Symphony No. 3 in C Minor, and Widor’s Symphony No. 3 in E Minor were examined to observe the techniques used by each composer to orchestrate for organ and orchestra.
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When French composer and conductor Hector Berlioz (1803-1869) first published his *Grand Traité d’Instrumentation et d’Orchestration modernes* in 1844, re-published by the author in 1855, it was intended to be the most comprehensive guide of its kind ever written. Advice was included on composing for every orchestral instrument known at the time. Berlioz described the sound of the high, medium, and low tessituras of each instrument, instructing his readers on which to use and which to avoid, and what sort of articulation sounded best in each part of the instrument’s range, as well as how to use it within the orchestral texture.

The organ is rarely used in symphonic compositions, but Berlioz—not an organist himself—included a chapter with descriptions of organ stops, registration, pitch range, and use with the orchestra. In order to do this, he must have interviewed one or more organists for their advice, but it is not known whom he consulted. One of the most interesting statements in his discussion concerns the unsuitability of combining the organ with the orchestra: “. . . the even and uniform tones of the organ can never fuse completely with the extremely variable sounds of the orchestra. . .” Later in the text, Berlioz wrote: “Whenever I have heard the organ together with the orchestra, the effect seems to be negative—diminishing rather than increasing the power of the orchestra.” He explained that the organ and the orchestra are like the Emperor and the Pope; they both want to rule.\(^1\)

In 1905, Richard Strauss (1864-1949) reissued Berlioz’s *Traité*, with his own commentary and clarifications interspersed between Berlioz’s original paragraphs. Strauss
wrote that Berlioz probably referred to a problem that was also encountered within the orchestra itself: “The clumsy and continuous employment of the wood-wind together with the brass results in a kind of dim and muddy color; the brilliance of the orchestra is lost, its power seems to be paralyzed. The organ, with its many wood-winds, has a similar effect. The reed stops, too, frequently impair the brilliance of the orchestral brass. Moreover, small differences of pitch—never entirely avoidable—add to the deleterious effect.”

To what did Berlioz refer, when he called the tones of the organ “even and uniform,” and the tones of the orchestra “variable?” In the original French, Berlioz uses the word sonorité, which has been translated as “tones.” The French word sonorité means timbre or quality of sound. While the English translation suggests a possible reference to timbre or overtones and the acoustic character of the sound, the original French text definitely refers to these qualities. Any questions raised about the direction of Berlioz’s thinking are settled by consulting the original text. The statements made by both Berlioz and Strauss about the decrease in orchestral power and brilliance must refer to the effects they heard when certain timbres were combined.

Our team was assembled, consisting of an engineer, a musician, and an engineer-musician. We wondered if the difficulties to which Berlioz and Strauss referred still existed today, or whether they had disappeared. No one knows the exact instruments Berlioz heard and wrote about, so there was no way to know whether we could have access to them. Many of the organs that existed in Berlioz’s day are destroyed, degraded through neglect, or renovated beyond recognition. We were less likely to find organs for
comparison than to find old, authentic orchestral instruments. Could we record modern musical instruments and hear what Berlioz and Strauss heard?

We decided to print out the sound spectra of various instruments, and those of various modern organ stops, hoping we would be able to see differences in the timbres that pointed to a problem in “blending.” At the least, we felt that we could investigate the acoustic qualities of organs and orchestral instruments, and we might encounter some discrepancies that fit the descriptions of the problems Berlioz and Strauss described.

We thought that perhaps an inability to blend was an inability to be in tune. Is it possible for the fundamentals to be in tune, but for the harmonics above them to be out of tune? In a trial recording session, using a flute and two different organ stops, we felt that there were audible pitches above the fundamental that sounded like they were out of tune. The flutist seemed to have to choose whether to tune to the fundamental or to tune to an overtone. This piqued our curiosity regarding the harmonic spectra produced by the design of musical instruments.

Most musicians, when encountering Berlioz’s statement about the incompatibility of the organ and the orchestra, are quick to point out that instruments have changed since Berlioz’s day. At that time, the Industrial Revolution was at its height, and the designs of musical instruments felt its effects. The changes made to most instruments since the mid-1800s involve efforts to increase volume and to improve tuning.

For purposes of exploration and discussion, our team chose four orchestral
instruments for their contrast in timbre and in method of sound production: violin, flute, oboe, and horn. The tuning and timbre of these instruments were compared acoustically with those of chosen organ stops, using quantitative measurement techniques. Our team intended to look for differences in tuning in the harmonic spectra, which may also have been Strauss’s “small differences of pitch (which) add to the deleterious effect.”

One of our chosen instruments had changed much less than the others since Berlioz’s treatise. The violin had reached its modern form in the seventeenth and eighteenth centuries, through the creations of such Cremonese masters as Antonio Stradivari (1644-1737) and Giuseppe Guarneri (1698-1744). The violin had changed from an instrument that lay upon the ground, and which the player bent over to play, to one held in the player’s hands. It had been given the characteristic “f-holes” in its body and had evolved into an instrument with four strings instead of six. The violin was (and is) the smallest of the bowed stringed instruments, and was held horizontally near the shoulder.4 The bow’s present form was the design of François Tourte (1747-1835).5

Theobald Boehm (1794-1881) developed the flute fingering and the mechanics to operate correctly spaced tone holes, based on mathematical (Pythagorean) calculations rather than the comfortable reach of the human hand, as had been the previous practice. Keys and levers helped to close off unreachable tone holes. Because of this improvement, Boehm flutes played more in tune than earlier designs. Boehm’s first experimental flutes date from 1828, and his first metal flute with a cylindrical bore dates from 1847. The 1847 model Boehm flute was officially introduced at the Paris Conservatoire in 1860.6
The oboe reached its accepted “Conservatoire” form in 1872, patented by Georges Gillet (1854-1920) and François Lorée (1835-1902). Changes in the bore, keys, tone holes, and reed were being made throughout Berlioz’s lifetime. Just as with the flute, these changes made the oboe’s design more mathematically correct. This improved the tone and tuning, and extended the range of playable notes.\(^7\)

The horn (also called the French horn) was also in a transition period in the early-to mid-1800s. The piston valve was invented by German Heinrich Stölzel (1777-1844) in 1816 and the rotary valve was invented by Joseph Riedl of Vienna (d. 1840) around 1832. Notably, these changes took place outside of France.\(^8\) The use of valves allowed players to change crooks without putting down the horn. Before valves were in use, horn players could only play in one key at a time. They could only choose from the notes in one particular harmonic series, determined by the length of the crook used. The available harmonic series could only be changed if the crook was taken off and replaced with one of a different length. No single crook allowed a player to sound all twelve of the pitches found in an octave. In the mid-18th century, the technique of partially stopping the bell with the right hand became widely used.\(^9\) This method allowed notes between the harmonics to be played, so the horn could play a melody instead of just the harmonic series. However, stopped notes have a different quality, so the notes in a melody might not match each other in timbre. Stopped tones can also vary, depending on how much of the bell is stopped. Berlioz warned against the tone of notes that required stopping the bell more than halfway. After he railed against composers of his day who wrote for the horn
with no regard for which notes would be open or stopped (a theme which resonates with most of his critical writings), Berlioz predicted that the horn with cylinder valves would probably be the instrument of the future.  

Just as many orchestral instruments were in a period of transition when Berlioz published his treatise, the organ was undergoing changes, due to a number of factors. French organ building had reached a peak during the Baroque period, with the organs of builders such as Alexandre Thierry (1646/7-1649) and Robert Cliquot (1645-1719). This style and time period is known as the French Classical organ school. The method of registration emphasized colorful solo stops and most registrations did not require large numbers of stops to be drawn.

The French Baroque period, with its prolific organ building, was followed by a great decline. This began after the French Revolution in 1789 and continued through the reign of Napoleon (1804-1814). A large number of the fine organs throughout France fell into disuse and disrepair, and many of their pipes were melted down for ammunition. This was the state of the art in France when Cavaillé-Coll came into prominence.

One of the most famous and admired organ builders that France has ever produced was Aristide Cavaillé-Coll (1811-1899). His first major contract was for the organ at St. Denis in 1841. This featured a device which became widely-used, the Barker lever, invented by Charles Barker (1804-1879). The Barker lever provided pneumatic assistance to the mechanical action of the organ keys, which previously had relied entirely upon the power of human fingers. Cavaillé-Coll built multiple wind chests with varying pressures,
producing a wide selection of stops of varying colors. Because of the assistance provided by the Barker lever, organists could more easily push down the keys when they used large numbers of stops at once. Cavaillé-Coll’s organs were especially known for their brilliant reeds. In as little as five years, with his 1846 contract for the organ at La Madeleine, his style of building and voicing progressed from a modified version of the French Classical organ to what became known as a “symphonic organ.”

When Berlioz first published his *Traité*, in 1844, Cavaillé-Coll was in the process of developing his style of organ building, between his first major contract at St. Denis in 1841 and what is considered his more mature building style, represented in the 1846 organ at La Madeleine. Berlioz re-published his treatise in 1855, when he should have known about Cavaillé-Coll’s progress (the two men were well-acquainted). However, it is impossible to know what organ(s) Berlioz wrote about when he wrote the organ chapter in his treatise, because he did not mention this information. We can only state that organ building was certainly evolving rapidly throughout Berlioz’s lifetime, and continued to do so afterward. He should have known about all the major organs of Paris, since that was where he lived for most of his life, and he knew the musical happenings of that city very well.

Because so many changes have occurred in most instruments since Berlioz’s day, it would be impossible to reproduce or even to conjecture as to what combinations of orchestral instruments and organs he might have heard. It is interesting to note that Richard Strauss, writing in 1905, believed that he could still hear and understand what Berlioz had described 61 years earlier, even with the subsequent changes in the
instruments. Now, 106 years after Strauss’s publication, with even more changes that have happened, especially to the organ, how can we examine the relevance of Berlioz’s statements for today’s musicians? We can document these differences and conjecture about whether our data match the descriptions written by these respected musicians.

Berlioz’s comment about the Emperor and the Pope describes full organ (all stops playing at once) combined with full orchestra. A full orchestra produces more data than can be analyzed or simply compared. The following spectrogram shows the multitude of complex peaks produced by all instruments playing different notes at once. The primary measurable quantity in this sample is the ensemble’s amplitude or volume. Direct comparison of individual instruments would be difficult, and hampered by the overall complexity of the data.

Figure 1. Sound spectrum of full orchestra. Reprinted with permission from John Atkinson.  

Sampling two instruments playing the same note greatly simplifies the analysis. This is what a conductor is trained to hear anyway—not just the ensemble as a whole, but also what is happening in individual parts.

With this in mind, we chose four orchestral instruments to compare to the organ: a violin, since strings are the backbone of the orchestra; a flute, since its shape and sound closely resemble organ pipes; an oboe, since its sound could be considered the most colorful (containing many overtones) in the orchestra, and it is also the instrument to which the whole ensemble tunes; and a horn, since it is the most difficult brass instrument to play, and has had challenges—mentioned above—with tuning and pitch for as long as it has belonged to the orchestra.

We chose to compare three different organs to these instruments: the Holtkamp organ at Knox Presbyterian Church, Cincinnati, in a fairly dry acoustical space; the Noack organ at Lakeside Presbyterian Church, in Lakeside, Kentucky, in a slightly more live acoustical space; and the Austin organ at St. Peter in Chains Cathedral, in Cincinnati, in a room that has at least five seconds of reverberation time. We used an 8’ Principal and an 8’ Reed on each organ. The Principal is a flue stop, a straight-sided open cylinder. The Reed has a metal tongue striking against another surface, with a conical resonator above that. We recorded each stop with each of our chosen instruments. The musicians were all professional, with practiced tone production, playing upon professional quality instruments. All instruments were recorded with each organ on the same day, so that the weather did not cause any great discrepancies. The musicians were given no instruction
regarding manipulation of tone or timbre. They were simply asked to “tune their pitch to the organ’s note.”

While most studies that have been published were undertaken to determine the perception of intervals between two different tones as consonant or dissonant—that is, whether the hearer perceives a major third as consonant, or a minor second as dissonant--their descriptions of what constitutes dissonance can also relate to a unison pair of pitches. In fact, this is often called an interval: “prime.” This interval is ubiquitous in ensemble playing and singing. An interval formed by the organ playing a note and another instrument playing that note can be called “prime.” In order to determine if these prime intervals were in tune, we examined the tuning of their harmonic series, as well as their fundamentals.

Our recordings were of instruments and organs playing only the A above middle C, which on most keyboard instruments is tuned to 440 Hz. This particular A is not always exactly A-440 on any organ; sometimes it is a little sharp, sometimes a little flat. However, since it was originally tuned to that frequency, it is usually close. Most orchestral players know this pitch so well that they can identify it in any situation. Our team wanted to find out whether there were identifiable problems with “blending” between present-day orchestral instruments and organs, at a very common and practiced frequency. We wanted to see whether dissonance between harmonics could cause this problem.

In order to compare the tuning of the chosen instruments, we used a technique
known as frequency analysis, which operates on the premise that a sound—such as a musical note—can be decomposed mathematically into its frequency components. *Frequency analysis* is a general term for the mathematical process known as *Fourier analysis*, after the mathematician Joseph Fourier, the first to show that any sound can be mathematically transformed and analyzed according to its frequency components.

A periodogram is a representation of a sound over a definite period of time. The frequency content of a sampled sound based on its periodogram is known as its spectrum. If a note has a strong component at a particular frequency, there will be a peak in the spectrum at that frequency (that harmonic will be louder). For any sounded note, the lowest strong frequency is called the fundamental (corresponding to the named pitch), and the softer pitches produced above it are overtones. While there can be many harmonic and inharmonic pitches of varying amplitude above the fundamental, our concern in this paper is with the integer multiples of the fundamental frequency. These are known as the overtone series or the harmonic series, and they are generally the loudest pitches that result from sounding the fundamental. If the term “overtones” is used, we refer to all pitches above the fundamental, harmonic and inharmonic. If the term “harmonics” is used, we refer only to the integer multiples of the fundamental. The first overtone is the first pitch produced above the fundamental, and the numbering continues from that point. However, the fundamental is the first harmonic, the next integer multiple is the second harmonic, and the numbering continues from there. This can be seen in Example 3 (below) which shows spectra of an organ Principal stop and an organ Reed stop. The line
marked “1” represents the fundamental. The fundamental is the first overtone, but it is the second harmonic. The term “harmonics” will be used as much as possible in this paper. The tone quality of any sound depends on which harmonics are produced, and how loud they are, relative to the fundamental.

The first example below shows a pure tone at A-440, produced electronically. As the diagram shows, a pure tone produces no harmonics.

![Frequency analysis of a pure tone plotted in level (dB) relative to the fundamental.](a) Spectrum and (b) acoustic pressure waveform for a finite segment of a pure tone, 440 Hz.

Examples of an organ Principal stop and an organ Reed stop are shown below. The line marked “1” represents the fundamental. Frequencies lower than the fundamental are background noise.
The upper diagram is the frequency analysis of a sound we would recognize as a Principal organ stop. It is a sound produced by resonance in a cylindrical open tube. The sound is smooth and spacious, rather than brilliant. The diagram shows that the strong overtones are only low ones, and the higher overtones are weaker (e.g., 30 dBs lower).

The lower diagram shows the frequency analysis of a Reed stop. This is the sound produced by a metal tongue vibrating and forcing air through an opening in an adjacent surface (the shallot), with a conical resonator extending above it. More upper overtones

Figure 3. (a) Spectrum of organ A-440 notes plotted in level (dB) relative to the strongest partial. (b) The acoustic pressure waveform used to calculate the spectrum.
are audible (louder) in this sound—the timbre is bright and “colorful.” The two examples in Figure 3 are typical spectra for these two types of organ pipes.

A spectrogram is an example of time-frequency analysis, an extension of frequency analysis, which is able to display changes in frequency content over time. Spectrograms provide a “fingerprint” of sounds. They allow us to distinguish one note from another in a musical passage. Jean Ville, in his paper of 1948, was the first to describe the need for a time-frequency technique for the analysis of music.

If we consider a passage [of music] containing several measures...and if a note, la, for example, appears once in a passage, harmonic [frequency] analysis will give us the corresponding frequency with a certain amplitude and phase, without localizing the la in time. But it is obvious that there are moments during the passage when one does not hear the la. The [frequency] representation is nevertheless mathematically correct because the phases of the notes near the la are arranged so as to destroy this note through interference when it is not heard and to reinforce it, also through interference, when it is heard...Thus it is desirable to look for a mixed definition of a signal...At each instance, a certain number of frequencies are present, giving volume and timbre to the sound as it is heard; each frequency is associated with a certain partition of time that defines the intervals during which the corresponding note is emitted.15

Jeremy F. Alm and James S. Walker note that spectrograms can be easily obtained using computer software, and they provide a modern way of implementing this “mixed definition of a signal” described by Ville.16 In essence, the spectrogram provides a moving
sequence of local spectra for the signal, describing the sound in the time-frequency plane. An example of a spectrogram derived from a musical passage is shown in Figure 4. The spectra for the musical notes are clearly delineated in sequence. The dark regions define strong signals from the fundamental and overtones of each note.

All of our recordings were made using Nakamichi CM-100 (cardoid) microphones in an X-Y configuration, positioned on a microphone stand approximately 4’ high. The sounds were digitized using a digital audio tape recorder (Sony TCD-D8 DAT recorder; 48 kHz sampling rate) and were digitally transferred to a PC for analysis. No conversion was necessary, since the raw data is compatible with a .wav format at the native sampling
rate. MatLab signal processing toolbox software (The Mathworks, Natick, MA) was used to analyze the recordings.

For each of the four instruments (flute, oboe, violin, and horn) chosen for comparison with the organ, at least three trials were recorded in each of the three locations: Knox Church in Cincinnati, Ohio; Lakeside Church in Lakeside Park, Kentucky; and St. Peter in Chains Cathedral in Cincinnati, Ohio. Two stops were used on each organ, an 8’ Principal, and an 8’ Reed with a conical resonator. For each trial, the recording consisted of a single note played by (a) the organ alone, (b) the organ plus the instrument, and (c) the instrument alone. This order allowed the instrumentalist to hear the organ’s pitch for five seconds and tune to it when they played their note. A-440 was chosen as the pitch for the notes, because it is the standard tuning note for orchestras when playing with keyboard instruments. Players were not instructed to play any certain way, except without vibrato. Each part of the recording, a, b, and c, was approximately five seconds in duration, from which a one-second sample was selected for

![Figure 5.](image)
frequency analysis. The sample chosen for analysis was well after the onset of the note which contains the most pitch instability, and was during the steadiest portion of the waveform. The selected segment was windowed and transformed to produce a frequency spectrum, using a fast Fourier transform (FFT) algorithm based on the periodogram. An example showing a typical recorded waveform and the segments used for analysis is shown in Figure 5, along with a spectrogram of the recording.

Each spectrum was analyzed using a peak-detecting algorithm to determine the frequency of the partials up to the eighth harmonic. This limit was chosen because the human ear is most sensitive to sounds within the 2000 to 4000 Hz band, or the range of human speech. The formula for the frequency of a harmonic is $n$ times the frequency of the fundamental, where $n$ is the number of the harmonic in question. Since we only used A-440 as our fundamental, the frequency of the eighth harmonic would be about $8 \times 440$, or 3520 Hz. Our recordings were thus unquestionably in the most sensitive range of human hearing. For each instrument combination (and location), a single trial was selected for further analysis, based upon which example showed the closest agreement of the fundamental pitch between the organ and the instrument.

Each instrument has a typical harmonic signature, which results from the manner in which the sound is produced, the shape of the resonator, and often the materials used to make the instrument. The skill of the musician does affect the sound, as do the pitch and the acoustic environments, but there always exists a general shape which is typical to any instrument’s harmonic spectrum. This set of harmonics allows a listener to recognize a sound as belonging to a particular instrument.
Figure 6. Spectra (a) and acoustic pressure waveforms (b) of the note A-440 played on flute, oboe, violin, horn, organ Principal and organ Reed plotted in level (dB) relative to the strongest partial.
The examples in Figure 6 show spectra and waveforms of the sounds used for comparison. The organ Principal and organ Reed examples show differences which would be heard in the timbre of two different organ stops, and which can clearly be seen in their spectra. The Principal has strong (loud) lower harmonics, but drops off sharply at the fifth harmonic. The Reed, on the other hand, has strong harmonics up to the eighth harmonic. There is a drastic difference to the listener in these sounds. The principal has a smooth, wide sound, and the reed has a bright, perhaps even strident tone.

Berlioz and Strauss accepted the existence of these differences in timbre, which have to do with the number of audible harmonics. Berlioz stated (above) that there were variations in some of these sounds that caused them to produce an undesirable ensemble blend when the organ was involved. Our team theorized that the spectra of the orchestral instruments might be different enough from those of the organ to be heard as dissonant.

In order to quantify any dissonances that we found, it is first necessary to understand what the human ear perceives as dissonance. If two pure tones sound at the same frequency, no dissonance is perceived. If the frequencies are moved apart, a slow beating, or amplitude modulation, begins to be heard. This is because the sound waves begin to interfere with one another. As the two pitches get farther apart, the beating becomes faster and the sound becomes rough (as opposed to clean and clear). At a certain point, known as the critical bandwidth, the two tones will be no longer be perceived as two notes that are out of tune, but as two completely different pitches. The distance constituting the critical bandwidth is not the same for every frequency, but is instead a
percentage of that frequency. Several experiments have been conducted to characterize the critical bandwidth as discerned by the human ear. A general formula for critical bandwidth, $B$ (in Hz), is given by Hartmann: where $F$ is the center frequency (the average frequency between positive and negative peaks in a waveform).

$$B = 24.7(1 + 4.37F),$$

(1)

This relationship is shown graphically in Figure 7.

![Figure 7](image.png)

**Figure 7.** Plot of the critical bandwidth versus center frequency. One-third-octave bands (dotted-line) are commonly used as a convenient approximation to human auditory filters; however, the critical bandwidths are narrower over nearly all frequencies.
A detailed study of “tonal consonance” and critical bandwidth was published by R. Plomp and W. J. M. Levelt. The overall findings are summarized by Thomas Rossing:

(1) If the frequency difference between two pure tones is greater than the critical band, they sound consonant; if it is less than the critical band, they sound dissonant.
(2) The frequency difference that gives maximum dissonance is approximately 25% of the critical bandwidth at that frequency.

Rossing also notes that:

In the case of musical tones, which nearly always have several harmonics...roughness can occur between the harmonics of the tones as well as between the fundamentals.20

Figure 8 shows the relationship between dissonance and the percentage of critical bandwidth proposed by Plomp & Levelt. In order to quantify the dissonance of each instrument combination, we use the standard curve to assign a relative value to each harmonic based on the observed difference in frequency.
Harmonics as well as fundamental pitches can be heard as dissonant. If a particular harmonic of one note sounds within the critical band of the corresponding harmonic of another note, but is not a matching frequency, these two harmonics together will sound noticeably dissonant, as will the pair of notes to which they belong. Twenty-five percent of the critical bandwidth is the point of maximum dissonance. The closer the difference in the harmonics comes to 25% of the critical bandwidth in question (but not over 25%), the greater the dissonance. If more than one set of corresponding harmonics have this characteristic, then the dissonance from each harmonic increases; that is to say, the
Our team endeavored to determine which of our recorded sounds had these dissonant characteristics within the most sensitive range of human hearing, and to what extent. For this purpose, we limited our examination to the first eight harmonics. The human ear has been found to discern up to six or seven harmonics. We included frequencies for one more harmonic to cover all possibilities. The most sensitive range of human hearing is 2000 to 4000 Hz, and the eighth harmonic of A-440 is slightly less than 4000 Hz.

Since a single instrument is usually not as loud as an organ stop, the amplitude values were mathematically adjusted to allow us to make comparisons. While it is true that dissonance would be much less noticeable between a loud note played by an organ and a softer one played by a single instrument, our objective was to look for differences in the frequencies of harmonics that would affect tuning. This could point to a basic dissonance between the organ and our chosen instruments. Such dissonance could be magnified by a group of instruments playing with the organ, each of which would contribute to the overall dissonance (because dissonance is additive).

Of the recordings with each instrument, we chose to examine the one that had the fundamentals of the organ and the instrument closest in frequency. We could then see that, if the fundamentals were even slightly different, there was great variation in the frequencies of the harmonics above that. Some samples showed an excellent “blend” with the organ stops, and other showed a possibility that they might cause roughness in the sound most or all of the time. It is necessary to remember in all samples that, while we
chose the most stable portion of the recording to examine, the quality of fluctuation that is
basic to sound waves (and probably desirable) causes the following calculations to have an
error margin of .4 to .5 Hz.

Our recordings with the Noack organ at Lakeside Presbyterian Church showed that
the best tuning matches there were the violin-Principal and the oboe-Reed. It is much
easier to see some of these minute differences with a column of frequencies rather than
with a graph. A graph large enough to show these would not fit on the paper.

<table>
<thead>
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<th>Lakeside violin/Principal</th>
</tr>
</thead>
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<tr>
<td>Harmonic: 1 2 3 4 5 6 7 8</td>
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<tr>
<td>Organ: 444.2 888.4 1332.6 1776.9 2221.3 2665.5 3109.7 3553.9</td>
</tr>
<tr>
<td>Violin: 444.2 888.2 1332.8 1776.7 2220.7 2664.9 3109.1 3553.0</td>
</tr>
</tbody>
</table>

The largest difference in frequency in the violin harmonics was only .9 Hz. The
fundamentals were exactly matched, and the next seven harmonics had differences less
than or equal to .9 Hz. (Remember that the margin of error is .5 Hz.) The critical
bandwidth for each of these eight harmonics gets wider as the frequency increases, so that
at the fourth harmonic (about 1760 Hz), 25% of the critical bandwidth is 54 Hz. The
difference in frequency at this point was only .2 Hz, which is negligible. Since harmonics
also get softer as they get higher, and frequencies beyond the fourth harmonic are not
audible for a Principal stop (see Figure 5), the upper harmonics have very little audible
dissonance, and sound very good together.

The largest frequency difference between the oboe harmonics and those of the Reed was .7 at the eighth harmonic. Even though the fifth, sixth, and seventh harmonics of a Reed stop are louder than those of the Principal, this difference is also negligible. At the frequency of the eighth harmonic, it is unlikely this slight difference is audible to anyone. These two notes match very well.

**Lakeside oboe/Reed**

<table>
<thead>
<tr>
<th>Harmonic</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
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<td>1774.1</td>
<td>2217.6</td>
<td>2661.1</td>
<td>3104.6</td>
<td>3548.0</td>
</tr>
</tbody>
</table>

At St. Peter in Chains, the best match with the Austin organ was the oboe with the Reed stop.

**St. Peter oboe/Reed**

<table>
<thead>
<tr>
<th>Harmonic</th>
<th>1</th>
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</thead>
<tbody>
<tr>
<td>Organ</td>
<td>439.8</td>
<td>879.6</td>
<td>1319.6</td>
<td>1759.5</td>
<td>2199.3</td>
<td>2639.3</td>
<td>3079.1</td>
<td>3518.9</td>
</tr>
<tr>
<td>Oboe</td>
<td>439.8</td>
<td>879.6</td>
<td>1319.5</td>
<td>1759.5</td>
<td>2199.5</td>
<td>2639.6</td>
<td>3079.5</td>
<td>3519.1</td>
</tr>
</tbody>
</table>

The greatest frequency difference for the oboe’s harmonics was .4 Hz, at the
seventh harmonic; there was a difference of only .3 Hz at the eighth harmonics. These are negligible percentages of the critical bandwidth.

At Knox Church, the oboe’s harmonics mapped very closely onto those of the Holtkamp organ’s Principal and Reed stops.

**Knox oboe/Principal**

<table>
<thead>
<tr>
<th>Harmonic</th>
<th>1</th>
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<th>7</th>
<th>8</th>
</tr>
</thead>
<tbody>
<tr>
<td>Organ</td>
<td>442.7</td>
<td>885.7</td>
<td>1328.4</td>
<td>1771.2</td>
<td>2213.9</td>
<td>2656.9</td>
<td>3099.6</td>
<td>3542.4</td>
</tr>
<tr>
<td>Oboe</td>
<td>442.5</td>
<td>885.7</td>
<td>1328.8</td>
<td>1771.5</td>
<td>2214.3</td>
<td>2657.2</td>
<td>3100.2</td>
<td>3542.9</td>
</tr>
</tbody>
</table>

**Knox oboe/Reed**

<table>
<thead>
<tr>
<th>Harmonic</th>
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<th>7</th>
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</tr>
</thead>
<tbody>
<tr>
<td>Organ</td>
<td>441.8</td>
<td>883.5</td>
<td>1325.3</td>
<td>1767.2</td>
<td>2209.0</td>
<td>2650.8</td>
<td>3092.5</td>
<td>3534.3</td>
</tr>
<tr>
<td>Oboe</td>
<td>441.7</td>
<td>883.3</td>
<td>1325.0</td>
<td>1766.6</td>
<td>2208.3</td>
<td>2649.9</td>
<td>3091.6</td>
<td>3532.8</td>
</tr>
</tbody>
</table>

In these cases, the oboe was only .1 or .2 Hz different from the organ’s fundamental, and this caused a difference of only 1.5 Hz at the most, at the eighth harmonic of the oboe-Reed sample. As well as being one of the softest harmonics in the eight, 1.5 Hz is still a negligible amount of the critical bandwidth for this frequency. It is interesting to that the oboe-Principal sample shows an exact match at the second harmonic, so it is possible that
the oboist was hearing that pitch and trying to tune to it. This frequency is an octave above the fundamental, a very strong harmonic on the Principal stop (see figure 5). In any case, these two samples do not seem to show any glaring difficulties in tuning.

The flute-Reed sample at Knox was very good, even though these two sounds have very different timbres. The greatest difference was 1.1 Hz, again for the eighth and softest harmonic on our graph. For the flute, this is not a strong frequency (see figure 5), and does not produce noticeable dissonance.

**Knox flute/Reed**

<table>
<thead>
<tr>
<th>Harmonic</th>
<th>1</th>
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<th>7</th>
<th>8</th>
</tr>
</thead>
<tbody>
<tr>
<td>Organ:</td>
<td>441.8</td>
<td>883.7</td>
<td>1325.5</td>
<td>1767.2</td>
<td>2209.2</td>
<td>2850.8</td>
<td>3092.7</td>
<td>3534.5</td>
</tr>
<tr>
<td>Flute:</td>
<td>441.8</td>
<td>883.5</td>
<td>1325.3</td>
<td>1767.2</td>
<td>2208.6</td>
<td>2850.8</td>
<td>3092.5</td>
<td>3533.4</td>
</tr>
</tbody>
</table>

The horn was also able to tune well with the Holtkamp organ’s Principal stop. The sixth harmonic is rather sharp, but again, this is a rather soft harmonic for both the horn and the Principal, so the two notes tuned very nicely.

**Knox horn/Principal**

<table>
<thead>
<tr>
<th>Harmonic</th>
<th>1</th>
<th>2</th>
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<th>8</th>
</tr>
</thead>
<tbody>
<tr>
<td>Organ:</td>
<td>437.3</td>
<td>874.5</td>
<td>1311.8</td>
<td>1749.0</td>
<td>2186.3</td>
<td>2622.4</td>
<td>3060.6</td>
<td>3498.0</td>
</tr>
<tr>
<td>Horn:</td>
<td>437.4</td>
<td>874.9</td>
<td>1311.8</td>
<td>1749.0</td>
<td>2186.3</td>
<td>2625.9</td>
<td>3061.3</td>
<td>3497.9</td>
</tr>
</tbody>
</table>
As evidenced above, some samples show very accurate tuning, particularly those involving the oboe. The horn-Principal combination at Lakeside did not work as well. The fundamentals were fairly close, with the horn only 1.1 Hz sharp. At the fundamental frequency, however, this is 6.1% of the critical band. By the fourth harmonic—one of the most audible—the difference is 5.8 Hz, and is sharp about 10.7% of the critical band. Since 25% of the critical band is the point of maximum dissonance, even 6.1% is noticeably dissonant, and 10.7% should cause even untrained ears to take notice. Oddly, the seventh and eighth harmonics are almost perfectly tuned. It is important to note though, that these harmonics are very soft, and may not be audible for either the horn or the Principal stop.

<table>
<thead>
<tr>
<th>Lakeside horn/Principal</th>
</tr>
</thead>
<tbody>
<tr>
<td>Harmonic: 1 2 3 4 5 6 7 8</td>
</tr>
<tr>
<td>Organ: 444.6 880.3 1334.1 1778.7 2223.4 2668.0 3112.6 3557.4</td>
</tr>
<tr>
<td>Horn: 445.7 889.5 1337.8 1784.5 2231.9 2677.6 3113.0 3557.2</td>
</tr>
</tbody>
</table>

The horn-Reed combination at Lakeside also did not match well. The fundamentals are 1.3 Hz apart (7.2% of the critical band), and the fourth harmonics are 6.3 Hz apart. This makes the dissonance at the fourth harmonic 11.66% of the critical band. Although the organ’s Reed stop has audible harmonics throughout the audible range, the horn’s harmonics are inaudible beyond the fourth harmonic (as mentioned above). The third harmonic is relatively loud on the horn and so probably even more important, and its
difference with that of the Reed is 4.1 Hz. This is about 7.6% of the critical band and produces noticeable roughness.

**Lakeside horn/Reed**

<table>
<thead>
<tr>
<th>Harmonic: 1 2 3 4 5 6 7 8</th>
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</thead>
<tbody>
<tr>
<td><strong>Organ:</strong> 443.5 887.0 1330.4 1773.9 2217.2 2660.7 3104.2 3547.7</td>
</tr>
<tr>
<td><strong>Horn:</strong> 444.8 889.9 1334.5 1780.2 2225.1 2670.2 3114.8 3557.4</td>
</tr>
</tbody>
</table>

While the violin was able to tune well with the Principal stop at Lakeside, the Reed proved to be difficult. The best sample we were able to obtain begins with the violin’s fundamental 1.5 Hz sharp to the organ’s (8.3% of the critical band), and by the fourth harmonic, the difference is 4.9 Hz (9.1% of the critical band). Since the strings, and the violins in particular, are the backbone of the orchestra, this does not bode well for the combination with full organ (which involves most or all of the Reeds, as well as the Principal ranks).

**Lakeside violin/Reed**

<table>
<thead>
<tr>
<th>Harmonic: 1 2 3 4 5 6 7 8</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Organ:</strong> 443.3 886.8 1330.1 1773.6 2216.9 2660.3 3103.6 3547.1</td>
</tr>
<tr>
<td><strong>Violin:</strong> 444.8 889.7 1334.1 1778.5 2222.7 2669.5 3113.0 3557.7</td>
</tr>
</tbody>
</table>
The violin was not a good match for the Principal or the Reed at St. Peter’s Church. Because the notes took 5 seconds or more to decay, the sound bounced around a great deal. It is possible that this aural confusion caused more difficulty than usual for the violinist.

**St. Peter violin/Principal**

<table>
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<tr>
<th>Harmonic</th>
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<tbody>
<tr>
<td>Organ:</td>
<td>439.8</td>
<td>879.6</td>
<td>1319.5</td>
<td>1759.5</td>
<td>2199.3</td>
<td>2639.1</td>
<td>3079.1</td>
<td>3518.5</td>
</tr>
<tr>
<td>Violin:</td>
<td>441.5</td>
<td>882.8</td>
<td>1323.9</td>
<td>1765.7</td>
<td>2207.2</td>
<td>2648.1</td>
<td>3091.2</td>
<td>3531.0</td>
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</tbody>
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**St. Peter violin/Reed**

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<tr>
<th>Harmonic</th>
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</tr>
<tr>
<td>Violin:</td>
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<td>882.2</td>
<td>1323.3</td>
<td>1765.5</td>
<td>2205.7</td>
<td>2646.6</td>
<td>3087.9</td>
<td>3528.8</td>
</tr>
</tbody>
</table>

At Knox, the horn-Reed combination was somewhat difficult. However, the first three harmonics tuned relatively well, so the seventh and eighth harmonics, which were the least accurate, probably are not that important.

**Knox horn/Reed**

<table>
<thead>
<tr>
<th>Harmonic</th>
<th>1</th>
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</thead>
<tbody>
<tr>
<td>Organ:</td>
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<td>875.2</td>
<td>1312.7</td>
<td>1750.3</td>
<td>2187.9</td>
<td>2625.4</td>
<td>3063.0</td>
<td>3500.4</td>
</tr>
<tr>
<td>Horn:</td>
<td>437.3</td>
<td>874.3</td>
<td>1311.8</td>
<td>1748.7</td>
<td>2186.8</td>
<td>2624.3</td>
<td>3060.2</td>
<td>3503.7</td>
</tr>
</tbody>
</table>
The violin-Principal combination at Knox was about the same as the horn-Principal. It may be considered worse, because the seventh and eighth harmonics are more audible for the violin’s note than for the horn’s (see figure 5). This means that more dissonant pitches would be audible at once, adding to the total cumulative dissonance.

Knox violin/Principal

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<thead>
<tr>
<th>Harmonic: 1</th>
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<tbody>
<tr>
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</tr>
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<td>1312.0</td>
<td>1749.0</td>
<td>2186.6</td>
<td>2623.7</td>
<td>3061.3</td>
</tr>
</tbody>
</table>

In general, the oboe and the flute were able to tune with the organ much better than the violin and the horn, and the horn has the advantage of fewer audible harmonics than the violin. Adjusting for the sharpness or flatness of pitch did not seem to make a difference for any of them. The flute and the oboe both have strong similarities to the construction of various organ pipes. The flute is an open cylinder, like the flue pipes of the organ. The oboe has a conical shape, like the resonators of many organ Reed stops. It is not surprising that these two instruments were able to tune to the organs. Woodwind instruments can also easily make many necessary adjustments with their embouchure. The horn is similar in that it is also a wind instrument, with a flared cylinder. Although its tuning might seem to be the worst of the four recorded instruments, it must be remembered that only the lower half of those harmonics are audible—the ones that are
higher are farther off, but so soft that they probably don’t matter. The violin also did not fare well in these trials. The fact that its sound is usually produced by bowing certainly could affect its relationship to all of these wind instruments. Its many audible harmonics add up to more dissonance.

The harmonics of all the instruments were fairly even multiples of their fundamentals. Any slight difference in the fundamental will create larger differences as the harmonics go higher, since they are multiples of the fundamental. When the fundamental was not an exact match with the organ, the resulting harmonics became more dissonant as they went higher. If two fundamentals are even a small distance apart, by the time these two frequencies have been multiplied by six or more (the sixth harmonic or higher), they are a noticeable distance apart and produce an unpleasant sound. Because dissonance is additive, several dissonant intervals are more dissonant than just one. Because the violin has more audible higher harmonics, this provides a greater number of opportunities for dissonance.

The following charts are visual representations of our results. The left column of Figure 9 shows the pitch differences between each orchestral instrument and the organ’s 8’ Principal stop at each of the three locations. The right column shows the percentage of critical bandwidth that these differences represent. Figure 10 shows the same data, with respect to the 8’ Reed stops on each organ.
Figure 9. Frequency differences for the fundamental (white bar) and overtones (shaded bars) through the eighth harmonic; 8’ Principal. (a) the absolute frequency difference between the organ and each instrument in Hz. (b) the same data represented as a percent of the critical bandwidth for each overtone.
Figure 10. Frequency differences for the fundamental (white bar) and overtones (shaded bars) through the eighth harmonic; 8’ Reed. (a) the absolute frequency difference between the organ and each instrument in Hz (b) the same data represented as a percent of the critical bandwidth for each overtone.

Pipe organs are very sensitive to changes in temperature and humidity. (Orchestral
instruments are also very sensitive to these factors.) This means that changes in the weather can affect the tuning of an organ. Also, if the temperature is not properly regulated in the sanctuary or hall, the tuning of the organ becomes unstable. Players of orchestral instruments who are performing with the organ must tune to an A that may be 440 Hz, or higher, or lower. A-440 has been the international standard for pitch since 1939. Berlioz was on a committee in 1859 that officially set A at 435 Hz. Before that, including both publishing dates of Berlioz’s treatise, concert pitch was even lower, and probably had great variation. Pitch standards had varied for many centuries before Berlioz’s lifetime. His warning about an organ tuned to a much different pitch is recognized by Strauss as being out of date. A greater challenge to orchestral players would be that pipes within a rank can be out of tune, and that the organist cannot adjust tuning while playing. This constitutes a “variableness” in the organ, rather than the orchestral instruments, however, and Berlioz warned that the organ’s notes were “even and uniform.” Although this is truly a problem, the statement about the Emperor and the Pope does not refer to it.

Another obstacle to tuning with the organ may be the voicing of individual ranks. This determines—beyond the characteristic shape and structure of certain pipes—the fine points of a pipe’s timbre. Mathematical formulas are not used to accomplish this. Organ builders and tuners use only their ears to judge the sound. When asked about harmonics and mathematical formulas, organ builders often refuse to discuss the subject, plead ignorance, or admit to studying these things long ago and forgetting them. It is not
surprising that there can be great variation in voicing among organs, even among instruments produced by the same builder. This is sometimes due to the organ’s purpose, whether it is installed in a small church, a large church, or a concert hall, and whether it will be involved in orchestral performances. If an organ is intended to be played with orchestral instruments, some builders claim that they will voice it to “blend” better.

One well-known organ builder explained the difference between how he would voice an organ for an orchestra hall and how he would voice an instrument meant to be used strictly for solo work. He said the difference was similar to the difference between a group of English choristers and an ensemble of opera singers at La Scala. The organ builder reasoned that the English choristers would blend much better because their sound has more harmonics, and the opera singers blend badly because they don’t produce as many harmonics. While this explanation seems to be inverted, it still makes a point. Opera singers are encouraged to strengthen the higher harmonics in order for their vocal timbre to “cut through” the orchestral texture rather than trying to sing louder in order to be heard. (It is true that there are singers that do not use this technique, but that subject would be a different paper.) The English choristers blend by concentrating on the lower harmonics, creating a “rounder” tone. This leads to a more homogeneous sound and does not cause individual voices to stick out of the texture.

When creating combinations of sounds, an organist usually chooses pipes at the fundamental pitch (8’ ranks). To this would be added pipes at one and two octaves above the fundamental, plus fifth-sounding ranks (in the second or third octave above the
fundamental, etc.). If a 16’ rank is available, this could be added as well, sounding an octave below the written pitch. A variety of these ranks would be sounding at once if the full organ is used, both flue pipes and reed pipes. This combination reinforces many of the lower harmonics for pitches throughout the registers. Much of the organ’s perceived power comes not just from wind pressure but from these reinforced harmonics. Adding harmonics above the fundamental serves to make the fundamental sound louder. Except for the fifth-sounding ranks, this method of registration is comparable to octave doublings in a large orchestration.

Strauss wrote that the horn blends with other groups of instruments better than any other instrument. Perhaps he did not include the organ in the “other groups of instruments.” The fact that the horn has very soft or inaudible upper harmonics could certainly help it blend in many situations, as there are fewer possible out-of-tune harmonics. Having fewer harmonics above the sounded pitch (which, in the case of A-440, is not actually one of the instrument’s fundamentals) would also serve to make the horn stick out less in an ensemble.

As mentioned above, our results showed that the flute and oboe were always able to tune well to the organ, and the horn and violin did not tune as well. This could mean that the horn and violin players were at fault. It would then mean that our flute and oboe players were more accomplished, but it still means that these woodwind instruments have the ability to tune reliably with the organ. In most large orchestrations, there may be two or three oboes, and perhaps the same number of flutes. There are usually four horns, but
many violins. If the difficulty in tuning extends to an entire violin section, that is a very large amount of additive dissonance. If there is a large group of violins, which would be the situation in a symphony orchestra, the violinists will hear each other more than any other instrument. Because of this, it is most likely that they will tune to each other, rather than to a far-away organ.

The sound of a violin section is extremely variable. If 20 to 30 violinists are playing at once, the human factor alone is a variable. The pressure of the bow on the strings can affect the harmonics of the sound, as can the distance from the bridge that the bow connects with the string. This distance includes the width of the hair on the bow, which can be narrower or wider, depending on the pressure exerted. In a large violin section, there are instruments from a variety of violin makers. Acoustic resonances will vary with the quality of the instrument. Factors of variability include the density of the wood with which the violin is made, the varnish used to seal the wood, the shape and location of the bridge, the positioning of the bass board and sound post, the material with which the strings are made, and the diameter of the strings. All of these variables will affect the sound spectra of violins. These considerations extend to all instruments in the family of stringed instruments, since they share the same design.

One of the most “even and uniform” qualities of the organ can be the wind pressure. Modern-day organs have a blower that is powered by an electric motor, which feeds a reservoir of pressurized air. This pressure is available whenever a key is depressed. This is not just a matter of constant volume, but of consistent vibrations of air within the
pipes. The tone quality of any note thus has less variation than one which depends on human breath and much less than that of a bowed string. In Berlioz’s day, the bellows did not yet rely on an electric motor, but wind pressures had to be high enough to support Cavaillé-Coll’s famed overblown stops. Producing sound by bowing and producing sound by forcing air through a pipe could still produce a striking contrast in uniformity of tone.

Another tuning issue that may need to be considered is the flute’s symphonic tessitura. While the oboes frequently play in the staff near our test note, the flute parts in a symphony are often at the top of the staff or above it. Since flutes tend to go sharp in the extremely high range, more exploration could be required concerning the tuning difficulties involved.

If it is not the inability of the organ to adjust pitch while playing, or to vary the timbre by lip or bow pressure, then is the “even and uniform” quality of the organ a problem of dynamics? Volume on the organ is controlled in two ways: the number of pipes sounding at once, and closing or opening the Swell shades. By the time Strauss edited Berlioz’s treatise, Swell shades were widely used. Berlioz commented that the organ cannot change dynamics gradually, and Strauss recognized this statement as being out of date. Berlioz reputedly knew Cavaillé-Coll, who made constant use of Swell shades and vents (levers used to add preset registrations) to produce a long, smooth dynamic change. It is remarkable that Berlioz did not acknowledge this.

Another monumental musician, and a giant in the world of organists, was Charles-Marie Widor (1844-1937). In his book, The Technique of the Modern Orchestra—A
Manual of Practical Instrumentation, first published in 1906, Widor addressed Berlioz’s characterization of the organ and the orchestra. Unlike Strauss, Widor treated the “blending” problem as the organ’s difficulty in changing dynamics quickly—a problem that was solved with the Swell shades. He stated: “So, here we are far from the supposed antipathy between ‘Emperor and Pope’ of which Berlioz speaks. No such thing exists nowadays, and a minute examination of the case leads us to doubt whether it ever really existed. Is not Berlioz’s ignorant guide to blame in this case too?”

Berlioz was not a pianist, much less an organist. He played the flute, the flageolet, and the guitar. Any knowledge he had of the workings of the organ had to come from acquaintances whom he interviewed. Widor was correct in attributing the information Berlioz’s gave in his treatise, at least in part, to an unknown organist or organists. According to Widor, this source was ignorant. A knowledgeable organist can create a registration that would go well with the orchestral sound. This is true to a certain extent, but Berlioz considered the problem to be one of full organ versus full orchestra. “Full organ” is not a discreet combination of well-chosen stops, but an opening up of the entire instrument. The sound will be whatever combination of stops the builder has supplied to the instrument. While Widor was arguably one of the greatest organists to ever live, he is not famous for his orchestration. Richard Strauss, on the other hand, may be considered a more knowledgeable source. It is necessary only to listen to Berlioz’s orchestral works (and to admit to their lasting success), to realize that he too is a reputable source when discussing orchestration.
Berlioz did not usually use the organ in his compositions. He did include it in his *Te Deum*, Op. 22, which was finished in 1849. It was premiered at St. Eustache in Paris in 1855. After describing the organ and the orchestra as the Emperor and the Pope, Berlioz advised composers to write for them in an antiphonal style, so that they would not be set in competition with each other, or have to try to “blend.” The forces required to perform the *Te Deum* are enormous, including two adult choirs, a children’s choir, many winds and strings, a large organ, and much percussion. For the premiere performance, the organ was at one end of the church, and the orchestra and choirs were situated at the opposite end. Berlioz followed his own compositional advice fairly consistently. With the forces situated as they were, and the organ at the far end of the aisle, the distance also makes antiphonal playing desirable.

Of the eight movements in the *Te Deum*, the organ plays only in movements I, II, IV, VII, and VIII. The first movement, entitled “Te Deum,” begins with loud, full chords, sounded antiphonally between the full orchestra and full organ (marked *Organo pleno*). This is in keeping with Berlioz’s instructions. When the organ enters next, six measures before rehearsal [2], many other instruments are playing. The organ plays long, sustained notes, and the registration is marked *Flauti*. This is obviously not full organ, but only wide-diameter Flute pipes, less brilliant than the Principal stop discussed above. This would also be the registration for the next organ entrance, 17 before [5], as there is no instruction to change. Both of these entrances are very short phrases for the organ, followed by long rests. In fact, the organ doesn’t play again for the remainder of the
movement.

The second movement, “Tibi omnes,” begins with an organ solo. The registration is still Flutes. The organ plays alone for sixteen measures, then twice trades four-measure phrases (antiphonally) with a small group from the orchestra and sopranos. The next entrances, at rehearsal [8], and eight measures after [8], are just small phrases to introduce the next section. The Flute registration continues. At one measure after [9], it looks like Berlioz has broken his rule, because the organ and the strings are playing together. However, the organ has long, sustained lines, using Flute stops, and the strings are playing pizzicato or a tremolo, so the notes are not really sustaining together. When the strings are marked “arco,” nine measures after rehearsal [9], the organ drops out. The organ has very little else to play in this movement—a four-measure solo at [10], the same thing at rehearsal [12], and a three-measure solo at the very end.

The organ plays again in the fourth movement. The registration still calls for Flutes only, and the organ plays antiphonally and concurrently with string pizzicati. Either way, the strings provide mainly percussive effects, so there is no question of blending. The organ does not enter again until four measures before [17]. Here, the organ merely provides a pedal point against legato winds and voices, and string tremolos, then one short imitative statement of only a measure and a half. There are three more short entrances in this movement: at [18], lasting about 4 1/2 measures; the one 18 after [18], lasting 2 1/2 measures; and the one in the last four measures of the movement. The registration is never changed from Flute stops, and the last entrance is partly antiphonal. The organ does not
challenge the orchestra here.

The organ plays again in movement VII, the Judex crederis. In this case, the registration is marked “Trumpets and Trombones.” While an organ registration could specify a Trumpet stop, or in this case, a Trompette, it is very odd to call for a Trombone stop. It should be called a Bombarde on a French organ. The organ used for the premiere of the *Te Deum* no longer exists, and it is unknown whether Berlioz composed with that organ in mind. This registration looks more like orchestral notation than organ registration. In any case, Berlioz seems to have requested reed stops at this point. There is a French tradition, dating from Baroque times, of drawing flue stops along with the reeds. This rounds out and fills out the tone. Although Berlioz did not write *organo pleno* here, and no dynamic is indicated, this looks like a rather loud point in the organ part, and full organ would be a good choice. This causes no problem, because the organ plays alone until the last measure and a half, where the winds interrupt with a *fortissimo* fanfare.

The next entrance for the organ is not until [38], after about 151 measures of rest. At this point, Berlioz did not write instructions for registration. All voices and all other instruments are marked *fortissimo*, so it is reasonable to assume that the registration still contains reeds. It could be pointed out that this entrance is not antiphonal and is basically full organ against full orchestra. The strings, however (which produced the worst blend with the organ), are playing tremolos almost exclusively, leaving the sustaining to the winds (which can blend perfectly with the organ). After two short chordal blasts, the organ rests again, returning at rehearsal [39] for just a measure and a half. This entrance

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seems a little unnecessary, but does happen at the apex of a crescendo, so perhaps the organ is meant to add power at that point.

Another argument for using reeds for the previous entrance is the marking *Flauti* at the entrance eight measures before [40]. Here, the organ is used mainly for pedal points, and it is doubtful whether it is meant to be heard. The effect is really one of depth, both of pitch and tone.

At [41], there is another strange registration instruction. Berlioz wrote *con Trombone e Bombardone*, which means “with trombone and bass tuba.” Berlioz was very fond of the bass tuba, but as an instrument in the orchestra rather than an organ stop. This seems to indicate that the organist should pull the lowest (and loudest) reed stops, along with whatever else is used. There is no change in registration for the rest of the movement. The organ has mostly short chordal interjections in this passage. What little remains must not have been meant to blend. It is interesting that Berlioz did not write for the strings to sustain the last chord with the organ. The strings sustain while the organ has short chords, then the strings cut off while the organ has a fermata on the last chord.

In the last movement, *Marcia*, the organ does not come in until the middle of the movement. There is no registration specified, only a marking of *forte*. Does this mean that the registration will be the same as before (*con Trombone e Bombardone*)? That would be much louder than *forte*, so the organist must decide what will work. The winds and the brass are playing, but many strings are doubling the organ. It might be a good decision to use many flue pipes, but no reeds here.
The organ is tacit until the last ten bars. At this point Berlioz specified *Organo pleno*, so there is no question—all stops should be drawn. It should be noted that the organ has long sustained notes, but the strings have shorter, faster note values or tremolos. This extends even to the organ’s last long chord—the tremolos continue.

When discussing works for organ and orchestra, Berlioz’s *Te Deum* would probably not be the first example suggested by most people today. The Symphony No. 3 in C Minor, Op. 78, written by Camille Saint-Saëns (1835-1921), is arguably the most popular example of such literature. No discussion of orchestrating for the organ and orchestra would be complete without this composition, written by a composer/organist who was one of Berlioz’s good friends.

This symphony has four movements disguised as two: there are really two pairs of connected movements. The organ enters 16 measures before Q. It serves as an accompaniment for the strings, which are unison and bowed. The organ is marked *pianissimo* here, so probably only soft Flute stops are needed. As it is not full organ and orchestra, this statement does not defy Berlioz’s rule.

The organ entrance at 15 after Q is much the same. Nine measures before S, horns, trombones, and one clarinet join, but this is still not full orchestra. At S there is one measure of full orchestra, but the dynamic is *pp*, as is the organ’s dynamic, so this is not problematic. It is interesting that Saint-Saëns wrote “*sans nuance*” at three measures before S. This indicates that while most other instruments have a crescendo/decrescendo
at this point, the organ is instructed to stay in the background. (The contra-basses have the same instruction.) This seems designed to make the organ “blend.”

The organ’s role does not change much for the rest of this movement. At five before U, where the strings have cresc., the organ has only poco cresc., so the organ is meant to remain in an accompanying role.

The organ entrance at seven after U contains some writing that is antiphonal with the winds, accompanied by pizzicati in the strings. This raises no issues, but there is an unusual marking at 16 after U. The organ is marked voix céleste. This is a registration marking. The voix céleste is a stop that is tuned slightly sharp, so that when it is combined with another stop (and it must be), a shimmer is produced by the slight dissonance. This is also a stop which is not used with large registrations. The effect would be lost in a mass of sound, besides which, no extra mistuning is desirable. There is no instruction for the rest of the movement to remove the voix céleste or to use another registration. It is possible that the organist would choose to change the registration, perhaps around nine before X, where the poco crescendo begins. It is also possible that Saint-Saëns meant to end the movement with the same shimmery, slightly out-of-tune effect that was established. That sound would be covered around seven or eight measures before X, as the strings crescendo, but it would again be evident slightly before X, and the movement would finish with this ethereal effect.

The organ does not appear again until the beginning of what many consider the fourth movement. The writing here is reminiscent of Berlioz. The organ has strong chordal
blasts and the orchestra answers. The organ has a *forte* marking, but most organists use full organ here. After a few soft, accompanying chords, the organ re-enters at eight before *T* with the theme (definitely full organ). This theme is played antiphonally with a fanfare in the winds. The strings play with the organ, but their chords are short and basically provide percussion. Saint-Saëns stretched Berlioz’s rule here but still maintained the effect Berlioz required.

At five measures after *U*, the organ has dropped back to *piano*. The winds have repeated eighth-notes, and the strings play *forte*. The organ’s role here is atmospheric—filling out the sound but not being noticed. This is even more true at four after *X*, where the sustained organ chords are marked *pianississimo*.

Some questions could arise at 16 measures after *AA*. The sustained organ chords are antiphonal with the strings at first, but sustained with the winds. The organ is marked one dynamic below that of the winds, and two below that of the strings, so that could be a helpful factor. Also, the entire orchestra is not combined with the organ. At 11 before *BB* this changes. The organ is marked *forte*, and all instruments play with it except low brass and percussion. As before, this could be a registration that involves reeds. This does not last—it is a short overlapping and the brass instruments do not play much. Perhaps the running eighth notes in the strings decrease the dissonance. The woodwinds are sustained, but they can tune with the organ more easily.

The long pedal point, which begins at seven after *BB*, is not much of an issue. It is
very low and very soft. The organist can choose a Flute stop that does not draw attention but provides a soft foundation for the strings and the solo wind instruments. This is also true for the sustained chords leading up to CC, which are marked ppp.

Beginning at EE the organ chords and pedal points are not intended to be in the background. For the rest of the movement the organ is probably pleno. Differences in “loud” and “extremely loud” can be made by using the Swell shades or by varying which reeds are engaged. This will depend on the organ and the organist. Between FF and GG, the excuse could be made that the strings have busy, non-legato figures. However, from GG to the end there are 21 measures of mostly full organ and full orchestra. There are many sustained notes in all parts. Saint-Saëns obviously thought that the combination of full organ and orchestra could provide a satisfying finale to his symphony. Being an organist, Saint-Saëns would have known how to register the organ to assure the most pleasing instrumental combinations, but there is not much choice when full organ is required. Saint-Saëns’s writing here seems to show that he does not entirely agree with Berlioz’s opinions on orchestrating for the organ and orchestra.

Richard Strauss occasionally used the organ in his compositions, as he did in Festliches Praeludium, Op. 61, and Ein Alpensinfonie, Op. 64. Strauss’s most well-known use of the organ (thanks in great part to Stanley Kubrick’s 1968 movie, 2001: a Space Odyssey) is in his tone poem Also sprach Zarathustra, Op. 30. The organ is used only in the first few sections of the work; after 88 measures, it is tacit for the rest of the piece.

Strauss’s writing shows that he did not agree with Berlioz about avoiding having
the organ and orchestral instruments play at the same time. There are no instances of antiphonal writing between the organ and other instruments in *Zarathustra*. Strauss did not hesitate to use the organ as another division of the orchestra.

Strauss made good use of the organ’s wide tessitura in this tone poem. In the opening, the organ has the same written low C as the contrabasses. This note can only be played by an instrument with a low C extension, so at least part of the contrabass section must have this extension. The low C written in the score will sound an octave lower when played by the contrabasses. Depending on the organ used, when this low C is played on the organ, it can sound two octaves lower than written. (This assumes that the organ has a 32’ rank in the pedal division, which is not unusual for an organ in a concert hall.) The note is marked *piano*, so a reed would probably not be drawn, only a flue rank. A note that low would be felt as much as it is heard. The organ is thus playing the lowest pitch and providing the foundation for the orchestra in the first 15-16 measures.

Measures 19-21 are the only place in the score where full organ is required (*volles Werk*). This would mean all reeds and flues are engaged, and the organ is sounding these at once with every other instrument in the orchestra. This adds to the strength and depth of the sound at one of the most famous climaxes in musical literature. It is interesting that the organ continues to sound in measure 21, when everything else has cut off. This makes a textural decrescendo. It also finishes the huge chord with a glittering organ sound, like the burn-off of fireworks.

After measure 21, the organ is marked *pianissimo*, and must use soft flue pipes—
probably Flutes. Much of the organ’s part in measures 24-26 is a doubling of other parts. Again, this adds depth to the sound, without vying for dominance.

At measure 27 Strauss instructed that the organ should have a very weak registration, so that it is accompanying the strings. (Die Orgel sehr schwach zu registrieren, so dass sie durch gängig als begleitend und die Streichinstrumente als führend erscheinen.) The organ’s dynamic here is pp, and the strings are marked p. In measure 43, the strings are marked f, and the organ is marked mf. In measure 54, the organ is marked pp, and the 1st, 5th, and 6th violas are marked p. This relationship continues throughout the organ’s part: the string section, or part of it, is always marked at least one dynamic above the organ. Most organists use a similar technique in registration—a Flute stop added to a String stop will “fill in the sound.” It adds depth and breadth.

Richard Strauss published his version of Berlioz’s Traité in 1905. Charles-Marie Widor published his manual on orchestration in 1906. Both gave their opinions about Berlioz’s strong views on the organ. While noting that some things had changed in a half-century, Strauss’s tone was respectful of Berlioz’s reputation as an orchestrator. Widor was less forgiving. An examination of Widor’s Symphony No. 3 for Organ and Orchestra, written in 1895, will show how he put his views into practice. (This is Symphony No. 3, Op. 69, for Organ and Orchestra, not to be confused with his Organ Symphony Op. 13, No. 3. It is curious that they are both in E minor.)

The orchestral theme at seven measures before [5] is a lyric statement in ¾ meter. This is answered by a 6/8 Allegro, beginning at [5]. The first entrance of the organ brings
back the ¾ meter theme, taking advantage of the organ’s sustaining ability. The organ brings back this theme twice in the measures before [9]. Each time, the organ is alone and the rest of the orchestra answers it. The contrast is furthered by a great dynamic difference between the soft organ entrances and the loud orchestral answers. Most importantly, this is a good example of antiphonal writing. The next organ entrance, eight measures before [13], develops the same theme, is answered by the orchestra with development of the 6/8 theme, and again is an example of antiphonal writing. The organ’s next entrance, at nine measures after [25], with the string statement at [26], forms a connection to the next section. These entrances also are antiphonal.

Up to this point it appears that Widor, no matter how he criticized Berlioz, actually complied with his method of orchestration for the organ. The statement that begins at five measures after [26] puts this theory to rest, however. At this point the strings and the organ have the same theme, at the same time, in homophonic rhythm. The organ is marked *forte*, which does not necessarily assume the use of reeds. The only helpful technique—from a “Berliozian” point of view—is that the strings are marked *piano*, so they allow the organ to dominate the texture. The strings then crescendo to *forte*, and the organ drops out. At four measures before [28], Widor resumed antiphonal writing. The pedal point at [29], against string tremolos, raises no controversy. The organ statement from three measures before [31] to seven measures after [31] is virtually a solo, so this also proves nothing. The organ entrance beginning at one measure before [33] contains hardly any overlapping.

The first proof that Widor disagreed with Berlioz occurs between [34] and [35].
The organ continues from the previous statement, but the dynamic has been reduced to *pp*. No registration is specified, but this would have to be some type of soft flue pipes, most likely Flutes (exactly what they would be always depends on the particular organ). The registration—and thus, the ability to blend—would depend upon the ear and the knowledge of the organist. This agrees with Widor’s argument. If the stops chosen are soft and delicate, the organ should have no trouble blending with the strings. This is necessary, as they both accompany a horn solo from [34] to [35].

Again, the organ entrance 11 measures before [36] is basically a solo accompanied just by timpani and some *pizzicati*. After [36], the D-flat pedal point is not an issue—it is much lower than the horn solo it accompanies, and the string tremolos and *pizzicati* provide mostly percussion (many quick attacks). This applies through the end of the movement. The organ’s one pedal melody at [37] sounds against the horns, except for a brave cello melody which provides a counterpoint to the pedal line. However, the organ will still be softer than the cello, as the organ is marked *cresc*, and the cello is marked *cresc molto*. This contributes to the “blend,” as does the fact that the organ registration has probably not changed. The pedal is marked “R,” meaning *Recit* or Swell, so the organ’s crescendo can be made using the Swell shades rather than adding stops.

In the second movement, the organ does not enter until three measures before [25]. It is marked *fff*, so reeds should be involved in the registration. The organ plays antiphonally with the full orchestra—only the timpani accompany the organ. This organ statement and orchestral answer happen twice more, but at [27] the full orchestra joins the
organ. However, the strings have either tremolos or *staccati* while the organ sustains.

Although the organ has a *decrescendo* two measures before [28], Widor has instructed that the reeds (anches) remain on the Swell. At [28], the strings play directly with the organ’s reeds and flues for four measures. It may be that the *Con brio* tempo and the fast string rhythms help this to work. The cellos and basses have legato lines together with the organ, but all the strings are marked a dynamic louder than the organ, which may also be helpful. This is not an instance of full organ and full orchestra, but it could still be an example of Widor’s alternate theory of orchestration.

For the next ten measures the organ is marked *piano* and the reeds are removed. There are woodwinds sustaining with the organ, but the strings have *pizzicati* or fast rhythms, so no “blend” is required from them.

From four measures before [30] a *crescendo* begins that reaches its climax at [32]. The organ has the reeds added again at the beginning of the *crescendo*. This implies the typical French Romantic way to make a crescendo—add reeds with the Swell shades closed, then add the Great stops (“GR” at [31] specifies this), then lastly, open the Swell shades. While this is happening, the full orchestra is also increasing in volume. By [32], full orchestra and fairly full organ have been playing together for a few measures.

From four measures before [33] until [37], the organ either rests or has soft statements with no reeds. The loudest entrance is at [35], where the organ is still accompanying the strings’ melody with flue stops.

Another full organ and full orchestra passage occurs at [37]. By nine measures
after [38], the organ registration specifies “Foundations and mixtures,” so the reeds are off by that point. Mixture ranks have varying numbers of higher pitches added to the notes played, reinforcing harmonics and certainly decreasing “blend.” While the organ plays with this combination, the strings accompany. This registration is indicated for the Swell. When the Grand Orgue or Great (“G”) is used, just before [39], it might not necessarily have the same registration. Widor has left this up to the organist, and he did so again at three measures after [40]. The dynamic there is piano, and it would be easiest to use a soft Flute or String stop to achieve this. The crescendo in the following measures does not arrive at a specified dynamic two measures before [41], so it is again up to the organist to judge how much the organ will be heard.

The Largo, which begins at [45] and goes to the end of the piece is like a grand finale. The organ joins the full orchestra with a dynamic of fff, so this must be full organ. This is the best example of Widor’s belief that the organ and orchestra sound well together; it is slow and 25 measures long. If there are questions raised by any other sections in this piece—articulation that makes instruments function more like percussion, only part of the orchestra playing together with the organ, or full organ and orchestra that only lasts for a measure or two—there is no question about this finale. Berlioz would not have written the piece this way.

The four works discussed above are examples of opinions and solutions displayed by four highly esteemed composers. Their compositions indicate what their educated ears heard. Our team endeavored to find acoustic evidence for the controversy and guidelines discussed by Berlioz, Strauss, and Widor in their treatises.
We found that there is noticeable dissonance between the organ and some sections of the orchestra. String instruments, with their colorful overtones, can have difficulty matching their timbre to the unchangeable organ stops. At the same time, this great possibility of variation also means a great possibility to adapt. Horns, too, sometimes have difficulty matching the organ’s pitch and timbre. However, the players can adjust their embouchures quickly. Woodwinds can instantly make minute adjustments to match the organ’s sound.

Rather than creating an obstacle, the “variability” of the orchestral instruments makes it possible for them to play with the organ, with its “invariability.” The mechanical and mathematical improvements to some instruments since Berlioz’s day have also made it easier. A capable organist, too, can help the “blend” of the ensemble, using his or her experience in registration combined with a sensitive ear. Many performers consider this a challenge worth accepting, because the organ can add a variety of additional colors and a greater pitch range to the orchestra.

The four composers above appear to agree on one thing: they were not afraid to compose for organ and orchestra. Their compositions show an understanding—admitted or not—of the difficulties involved. They avoided many of them.

Was Berlioz right? Would he retain his opinion today? Widor wrote: “If Berlioz were still alive he would forswear his views of yore, or rather the views that were so unfairly instilled into his mind. Admirable new effects may yet be drawn from the union of the two former rivals, ‘the Emperor and the Pope,’ who, converted into fast allies, manifest ever growing mutual sympathy.”35
ENDNOTES


2 Berlioz and Strauss, 245.


9 Thomas Bacon, history2.

10 Berlioz and Strauss, 260.


14 Atkinson.


21 Plomp and Levelt, 556.
22 Rossing, 140.


24 Rossing, 112.

25 Berlioz and Strauss, 246.

26 Widor, 140-141.

27 Berlioz and Strauss, 260.

28 Bennett, 156-220.

29 Berlioz and Strauss, 245.

30 Widor, 140.

31 Widor, 143.


33 Widor, 140-144.

34 Berlioz and Strauss, 244.

35 Widor, 144.
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