THE CHORAL CONDUCTOR AND ACOUSTICS:
IMPLICATIONS OF RESEARCH FOR
CHORAL/ORCHESTRAL SEATING ARRANGEMENTS,
ESPECIALLY AS ADAPTED TO A PERFORMANCE OF
A. L. WEBER'S REQUIEM AT TRINITY PRESBYTERIAN
CHURCH IN TUCSON, ARIZONA

by

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I hereby recommend that this document prepared under my direction by Randy Keith Pennington entitled:

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Chapter I

Introduction

Most choral conductors, at some point in their career, will be faced with the prospect of performing a composition that utilizes both voices and instruments. There is a considerable amount of material to turn to for assistance in the areas of gesture, instrumental conducting terminology, and suggestions for improving communication with a group of instrumentalists. However, very little information is available to help determine proper placement of the musicians for performance. This aspect is critical since one of the major difficulties in dealing with instruments and voices is achieving a dynamic balance between the two forces. Too often the method of obtaining an acceptable balance is limited to the conductor imploring the orchestra to play as soft as possible and the chorus to sing louder. Frequently, especially in large choral/orchestral performances, subtle nuances which have been carefully rehearsed seem to either be disregarded or sacrificed during the performance.

The purpose of this study is to provide the choral conductor with information on seating arrangements, acoustical properties of voices, instruments and architecture, and demonstrate how, utilizing this material, a seating arrangement for Trinity Presbyterian Church in Tucson, Arizona was designed. It is hoped that this study
will provide information which will assist the conductor in making knowledgeable decisions concerning the placement of musicians toward a more satisfactory dynamic balance.

The study has some important considerations. First, the research examined to determine the seating arrangement, particularly in the area of acoustics, is of a nature that it can be adapted to other concert locations. Second, the acoustical research examined to create the seating arrangement is such that changes in the seating formation can make a difference. Acoustical phenomena of music that can not be altered by the adjustment of position are not considered.

The language of the study is such that it can be comprehended by any intelligent individual, not simply experts in the field of acoustics. There has been a careful attempt to avoid using terminology that needs definition, unless it is critical to the understanding of the acoustical concepts utilized.
Chapter II

Seating Arrangements

Historical Research

The building of a seating formation based on acoustics begins with a study of current and historical seating arrangements. Deliberations concerning where voices and instruments should be placed is not a new issue. One can find references to this dilemma throughout the course of music history. For instance, Wagner and Berlioz, among others, have made extensive comments. The issue has become more complex in recent history, however, due to the increased separation of the roles of conductor and composer. This separation of roles has made it difficult for the composer to oversee all aspects of a particular performance.

Prior to the nineteenth century most compositions were composed with a specific concert location in mind. Composers could utilize a known architectural design and their aural sense of proportion and balance to create a composition. For example, Johann Sebastian Bach’s St Matthew Passion and many of his cantatas were composed for performance in the Thomaskirche. These compositions, and many others which were written prior to or during this time, were composed for a specific situation and acoustical setting. Giovanni Gabrieli’s numerous polychoral compositions present us with other viable examples. These
works were composed for, and utilized to the fullest, the architectural design and acoustics of St Mark’s cathedral in Venice.

The problem of placement being investigated in this study has more direct ties to the nineteenth and twentieth centuries. This is due to; 1) the refinements in instrument construction which have increased, among other capabilities, the dynamic range of the instruments; 2) the basic sound idea of the Romantic era which, in choral/orchestral compositions, often placed an emphasis on the use of larger forces; and 3) the increase of non-staged compositions written specifically for chorus and orchestra for the concert hall. Refinements in instrument building have increased the difficulty in achieving a balance between voices and instruments. This problem is heightened due to the large number of instruments now considered appropriate for a symphony orchestra. The increase of choral/orchestral compositions written for the concert hall has changed the manner in which choirs have been utilized in compositions. This has created, among other problems, space and logistical concerns for most performances involving a large number of musicians for a performance.

One of the more prolific and ardent writers on the importance of proper seating formations during the nineteenth century was Hector Berlioz. In his treatise The Conductor, translated by John Broadhouse, he makes special mention of the conductor’s responsibility in determining the
physical arrangement of the chorus and orchestra for performance. He is explicit concerning the exact placement of the orchestra and chorus stating:

The instruments (should) be arranged on the steps as follows: the first violins should be in front on the right, the second violins in front on the left; the violas in the middle between the two violin groups; the flutes, oboes, clarinets, horns, and bassoons behind the first violins; a double rank of second violins, the trumpets, trombones and tubas behind the violas; the rest of the violoncellos and double basses behind the woodwinds; the harps in front, close to the conductor; the drums and other instruments of percussion behind the brass; the conductor's back should be towards the public, at the bottom of the amphitheater, and close to the desks of the first and second violins. . . . There should be a horizontal platform of greater or lesser size, extending in front of the first stage of the amphitheater: on this platform the choristers will be placed in fan-like form, three parts turned towards the public and all able to easily see the conductor. The grouping of the singers by voices will vary as the author has written for three, four, or six parts. In all cases the ladies, sopranos and contraltos, will be in front seated; the tenors behind the contraltos, and the basses behind the sopranos. 1

J. J. Quantz, an earlier figure in music history, demands from the "leader of the music (that the) instrumentalists are well allotted into their places." 2 He then gives specific instructions for the arrangement of the


2 J. J. Quantz, Versuch einer Anweisung die Flote traversiere zu spielen, (Berlin, 1752)
players. Wagner had a new platform especially built for him in Paris for a performance of Beethoven's *Ninth Symphony* so that he could arrange the orchestra on steeply rising tiers. It is obvious from these observations, and other musicological research, that conductors and composers have considered the placement of forces critical to the success of a performance.

Twentieth-century composers, although generally utilizing smaller forces, have been quite specific concerning the placement of personnel. It has now become commonplace for composers, especially for compositions involving spatial effects, to include charts or instructions indicating the stage arrangement for personnel and instruments. An example of such a composition is Penderecki's *Passion According to St. Luke*. These directives, although useful for specific compositions, do not address the issue of personnel placement for the majority of compositions that are a part of the repertoire of choruses and orchestras in this century. Conductors, when performing most works, must turn to traditional formations or their own aural sense for proper placement. To determine proper placement of musicians, the conductor can first examine traditional formations for orchestras and choruses.

**Orchestral Seating Formations**

In figure 2.1 we see two traditional formations used by orchestras for string placement - the
European and American String Arrangement

German seating arrangement

American seating arrangement

Variation of the American arrangement

From Meyer: Acoustics and the Performance of Music
German and American versions. These remain the most common, although there are many subtle variations. The basic difference between the two involves the placement of the violins, specifically the first and second violin sections. The first historical forerunner of the German seating arrangement may be found in the Mannheim church orchestra under the Abbe Vogler around 1777. He introduced the separation of the violins to the right and left sides. The center between the two was given over to the continuo. Although the arrangement of the two violin sections on each side was quickly taken up by other orchestras, the German seating arrangement did not come into common use until around the second half of the nineteenth century. The advantage of this arrangement is the close physical contact between the violins and the cellos. The added benefit of a stereo effect is possible when the music includes answering motives between the first and second violins.

The American seating arrangement is based on a suggestion by Stokovsky. It became particularly popular in Europe after World War II. The arrangement is similar to the linear pitch succession from left to right of a string quartet. Good contact between the first and second violin sections is allowed with this arrangement. A variation of the American seating position, introduced by Furtwängler, interchanges the positions of the cellos and doublebass. Unfortunately, there are disadvantages in this position
since the distribution of the second violins and violas over
the whole width of the orchestra has a tendency to overpower
the first violins.

Figure 2.2 shows the two most common formations
for the entire orchestra - the traditional and the modern
symphony arrangements. The principal differences between the
two involve the positioning of the second violins, cellos
and basses. Elizabeth Green, in her book The Modern
Conductor, discusses the two formations. She states:

Four things must be observed in all orchestral
setups: 1) the first violins must be on the
conductors left; 2) the first chairs in the
woodwinds are grouped in the center with the
sections spreading outward from them; this is
for efficiency when only solo winds are called
for in the score; 3) the trumpets are usually
seated so that they blow somewhat across the
orchestra, not directly toward the audience;
(and 4) the basses should stand behind the
celli, since they double the cello line an
octave lower almost constantly. 3

Green's placement of instrumental groups, i.e the
brass, woodwind and string sections, is quite similiar to
the overall structure suggested earlier by Berloiz. The
individual placement of instruments within an instrumental
group is based upon tradition, the tastes of the conductor,
and the affect that individual instruments have on other
instruments within a group. For example,

consider the placement of the french horn
within the brass section. The adjustment of
intensity is easily upset if the trombones
are seated behind the horns, because the player

3 Elizabeth Green, The Modern Conductor, 2nd ed.
FIGURE 2.2
TRADITIONAL AND MODERN SYMPHONY ARRANGEMENTS

Traditional Symphony Arrangement.

Modern Symphony Arrangement.

from Green: The Modern Conductor
in each section hears the other section more loudly than their own. This domination of the other instrumental section in the ears of the players also results in the musicians thinking that a request by the conductor to reduce loudness does not apply to them.

It would therefore seem to be more advantageous to arrange the trombones behind the woodwinds than the horns. The added benefit of such an arrangement would be the close contact between the leaders of the trumpet and trombone sections and the solo players in the woodwinds.

There is, of course, no universally agreed way of placing the orchestra. Some conductors, such as Furtwängler, are known to change the seating position for each concert dependent upon the acoustical qualities of the hall. Other conductors insist on retaining the same seating position with each orchestra they conduct, despite the arrangement to which the orchestra has become accustomed.

Choral Seating Formations

There are a variety of commonly used formations for a cappella chorus. These arrangements are dependent upon the kind of chorus -- whether men's, women's, or mixed -- the ability of the individual singers, and the numerical balance between voice parts. In general, these formations can be divided into two basic categories: 1) arrangement by section (or voice part) and; 2) mixed seating.

---

Sectional Seating

Figure 2.3 shows three sectional seating plans for mixed chorus. All are standard and their use is based upon the tastes of the conductor, or, as mentioned before, the musical ability or numerical balance of the chorus. Example one shows a common arrangement with the outer voice parts, the soprano and bass, positioned on the conductors left while the inner parts, the alto and tenor, are positioned on the right. Conductors who use this arrangement feel that the proximity of the soprano and bass sections provides a certain stability to the harmonic structure and aids intonation. Some conductors use a slight variation of this arrangement as shown in example two. This places the inner parts, the parts most frequently perceived to be underbalanced in homophonic music, in an advantageous position for projection and dynamic control through the conducting gesture.

Example three shows a variation which places the male voices in the center. This formation is primarily utilized when either the number of male singers in the group is small, or the ability of the male singers is less than desirable. Example four shows a variation of the same concept, with the female voices intersecting across the rear of the chorus while the male voices remain in the front.

"This seating arrangement, in which the treble voices literally surround the male section, increases the (men's) awareness of the treble parts and provides increased tonal
FIGURE 2.3
SECTIONAL SATB SEATING FORMATIONS

EXAMPLE 1
from Pfautsch: Choral Conducting A Symposium

EXAMPLE 2
from Ehmann: Choral Directing

EXAMPLE 3
from Green: The Modern Conductor

EXAMPLE 4
from Bodegraven: The School Music Conductor
support for the male section." 5 Common variations to these basic plans can be noted in figure 2.4.

Seating by section is the most common arrangement for choruses. Many conductors use this arrangement because they feel it provides a better balance and blend. Other conductors stress that one of the factors determining their choice of sectional seating is the need for individual line separation, particularly in contrapuntal music. Seating by section helps to emphasize the horizontal rather than the vertical elements of the music. Some conductors insist that sectional seating allows music, especially compositions which incorporate imitative entries and manipulates motivic material, a clearer separation of line. It also allows the unique personality of each line to be represented. Conductors who stress this point feel that singing polyphonic music from the anonymity of a mixed ensemble tends to blur this identity and diffuses the necessary separation of line.

This arrangement often has a tendency to reduce the individual colors of the voice into one color per section as the individual voices take on the characteristics of those around them. This is because the singers in each section are producing tones at the same frequency level.

SECTIONAL SATB SEATING VARIATIONS

FIGURE 2.4
This 'soaking up' of the sound, however, can be advantageous in producing a better blend. Derel Johnson states:

When there are many voices in the choir, voice qualities can be found which will filter out the undesirable sounds. Those voices that are good filters can be placed in front of or next to offending voices, causing the rough edges of the total choral sound to be smoothed. 6

In actuality, this arrangement does give the conductor more control over the immediate balancing of the group through gesture. David Stocker addresses this issue when he states:

The more we become expressively interpretive the (more) satisfactory a sectional arrangement becomes. Since the conductor cannot adequately signal a part to do something different (in a mixed formation) he is no longer able to shape the music. When he cannot shape the music he has ceased to make the concert a creative experience and the choir is now conducting him. 7

Mixed formations

The most common formations that do not employ sectional seating for choruses are mixed formations. Two of the more popular formations of this type are the "scrambled" and the "mixed quartet" arrangements. The scrambled formation involves placing each singer as far apart as possible from another singer singing the same part. The mixed quartet arrangement is the placement of singers by


quartet. The use of mixed formations has become fashionable since the advent of the professional touring choirs of the forties, fifties, and sixties. Some of the more prominent conductors who have espoused this type of arrangement include Fred Waring, Robert Shaw, Norman Luboff and Richard Wagner. An example of each is provided in figure 2.5.

The mixed quartet arrangement is simply the placement of the choir members by quartet: SATB or any combination thereof. Conductors who use this arrangement believe that the end result is the achievement of a better balance and blend since each singer is an integral part of a mini-ensemble within the main chorus. The cellular aspect of the quartet arrangement aids the singer both technically and psychologically. Quartet singing reduces the likelihood of loss of pitch for the entire choir if one individual is singing under the pitch. In a sectional arrangement an individual who tends to sing flat has more opportunity to disturb the pitch of the chorus through influencing the pitch in his/her particular section. When individuals are singing in a quartet formation they are able to hold their pitch more satisfactorily. This is because they are singing different parts, rather than trying to match the exact
FIGURE 2.5
SATB MIXED FORMATIONS

MIXED QUARTET FORMATION
EXAMPLE 1

from Garretson: Conducting Choral Music

EXAMPLE 2
SCRAMBLED FORMATION

from Diercks: "The Individual in the Choral Situation"
The Choral Journal
frequency of the singer next to them. Louis Diercks summerizes this concept by stating:

Each singer is a receiver as well as a sender, and each tends to react to what he receives. The more sensitive (singers) are more readily influenced than the less sensitive (singers). 8

The 'scrambled' setup, so designated by Diercks, involves placing each singer as far as possible from another singing the same part while still maintaining an acceptable distance from one singer to another for good ensemble. Diercks, in his article "The Individual in the Choral Situation," promotes this type of arrangement and cites several rationale for its use. He suggests that an important phenomenon occurs when listening to more than one singer on a voice part at a time. He writes:

when singer A and singer B sing together the resultant is not A + B, but something more or less. This is true even though they sing the same pitch. (Since) each of these singers is a receiver as well as a sender (they) tend to react to what (they) receive and this reaction causes a change in what is sent. 9

In the same article, E. Milton Boon provides mathematical justifications for Diercks' theory concluding that when two individuals sing at the same time some of the "amplitude may


be reinforced (while) others (are) attenuated. The resultant response is therefore certainly not \( A + B \), but something far more complex." 10

Directors who use a scrambled setup believe it aids the singer in hearing their own vocal production and allows them to rapidly and accurately evaluate their efforts toward improved tone quality, diction, balance, blend, and intonation. According to Robert Garretson:

One of the results of this arrangement is improved balance and blend. The weaker singers are not in a position to affect the others in the section adversely, all singers can hear themselves better and, with the sound of any particular part coming from all areas of the choir, there seems to result a better fusion of sound. 11

The mixed quartet arrangement obviously requires a more equally balanced group in terms of voice parts than the scrambled. Both of these arrangements are based upon an approach to choral blend in direct opposition to the sectional seating plan. In this kind of formation the singer has more responsibility for producing a blended and balanced sound. Conductors who utilize these arrangements frequently stress the importance of allowing the individual colors of

11 Garretson, Conductor Choral Music, p. 289.
each voice to be apparent, blending into a unified whole. As Diericks states:

(these) setups admit the uniqueness of the individual singer. (Singers) are not asked to sound the same as another nor to be at the exact same dynamic level. . . . The singer is cherished as an individual. 12

Choral/Orchestral Arrangements

Figure 2.6 shows the most common formations for combined choral/orchestral performances. These are based primarily upon tradition and space concerns. Most explanations regarding the reasoning behind such formations are vague at best. For instance, F. W. Wodell states that "when both orchestra and chorus are engaged in a performance, it is usually best to seat the chorus in such a way that a goodly proportion of the voices are as near the audience as possible." 13 Very little attempt, except in a general fashion, is made by authors to address placement of the chorus and orchestra. Most research, while providing justifications for formations intended for either chorus or orchestra alone, does not provide explicit explanations for choral/orchestral formations. Some simply do not discuss the problems associated with the combination of voices and instruments. A common element, when it is discussed, is the


FIGURE 2.6
COMMON CHORAL/ORCHESTRAL FORMATIONS

Tenor          Bass
Soprano        Alto
Orchestra

Tenor          Bass
Soprano        Alto
Orchestra

Tenor          Bass
Soprano        Alto
Orchestra

from Thomas: The Choral Conductor
insistence to keep the chorus, as a unit, separate from the orchestra. Kurt Thomas, in his book *The Choral Conductor: The Technique of Choral Conducting in Theory and Practice*, suggests avoiding division of the chorus into segments separated by the orchestra, or placing the chorus too far from either the listener or the orchestra. He indicates that too much distance from either the conductor or the orchestra is not advantageous to the entire ensemble sound.

One common element in all choral formations, whether sectional, mixed, or choral/orchestral, is the use of a semicircular form in the setup. This allows for good contact both visually and aurally between the musicians. It also speaks to the need for the ensemble to look and feel like an ensemble. As Wilhelm Ehmann states:

> the placement of the various sections of the choir should be regulated in such a way that the choir's awareness of its corporateness is preserved. The placement of the various sections should be thought of as a redistribution and a rearrangement of a total body-soul organism. 14

He goes on to discuss the importance of a circular or semicircular form for the arrangement of the chorus citing both historical and psychological concerns. He states:

> according to descriptions and engravings the singers in traditional choirs were placed in a circle or semicircle around a large music stand. The circle is a symbol of unending motion.

---

like the old unceasing motion of polyphony. The circle formation is also the best solution for ideal music making; all singers can hear and see each other constantly; the musical circuit is closed, and the body-soul activity can proceed without interruption.

Now that we have an ideal of some of the common formations in use, as well as the logic behind their employment, we can turn our attention to the study of acoustics and how research in this area may affect personnel placement.

Chapter III

An Overview of Basic Acoustics

Acoustics is a complicated field that encompasses many different areas and topics. In this document, we will focus on those acoustical elements that have the greatest propensity for change when the seating arrangement of the musicians is adjusted. Before we discuss specific acoustical elements, we need to review some basic concepts of acoustics and define some terminology important to the study.

How Sound is Transmitted

One of the most basic concepts in acoustics, and one which is critical to our discussion concerning the

placement of musicians, is the process whereby sound is transmitted. Sound is simply a sensation produced by vibration. More specifically, it is the sensation experienced when vibrating air particles touch our eardrums.

There are three things that are needed to produce sound. First, we need something, in this case instruments or voices, to produce a vibration. Second, we need some medium to convey these vibrations from the source to the receiver, in this case air. Third, we need something to collect these vibrations and transform them into the sensation we call sound. The ear and brain act as our receptacle and transformer.

When an object, say a string on a violin, is struck it begins to vibrate causing a disturbance in the air molecules around it and creating what is termed a sound wave. A variety of factors can affect the attributes of a sound wave: frequency, intensity and the shape of the vibrating object, just to name a few. The concept important to this study is that whenever we hear a noise it is a product of a sound wave. This is what our receptacle, the ear, was engineered to receive. The understanding of how sound is transmitted from the source to the receiver is important since the specifics of this study concentrate primarily on sound waves; their directional characteristics, how they are reflected and absorbed by various structures and materials, and how they are ultimately received by the listener and stage musician.
In figure 3.1 we see a simplistic example of a sound wave emitted from a vibrating object as it moves toward a plane wall. In this example "S" equals the source of the sound. It must be understood from the outset, despite the two-dimensional drawing, that sound waves tend to spread continually in every direction. Thus, any vibrating body gives rise to spherical waves. This characteristic of sound spreading out in spherical waves is called diffusion. If we can imagine the action taking place in figure 3.1 as proceeding outward in every direction from the source, rather than just in one direction, we can visualize the formation of these spherical sound waves. Bartholomew explains sound waves by using the analogy of a bomb. He states:

When (the bomb) explodes, it pushes back the surrounding air in every direction, crowding the air particles together, so that a sphere of compression is started outwards, followed by a sphere of relative rarefaction, where the particles are farther apart than normally. Due to the inertia of air, it is not set into motion as a whole. The particles farther away do not respond as soon as the first ones. Consequently, the air is crowded together or compressed immediately around the source. This compressed condition - followed, of course by a rarefaction (and by other compressions and rarefactions, caused by repeated vibrations) - advances outward through the elastic atmosphere with a definite speed which may be taken roughly as 1100 feet per second, or 750 miles per hour. 16

One of the elements that affects sound waves is frequency. Frequency is simply defined as the number of

FIGURE 3.1

SIMPLE SOUND WAVE

from Bartholomew: Acoustics of Music
complete vibrations that an object produces per second. Letus return to our example of a string being struck. When it is put into motion by being struck it first moves in the direction it was pushed and then back in the opposite direction. A longer string takes more time to complete this back and forth action. A shorter string completes the cycle more quickly, and thus vibrates faster. Frequency is the number of cycles per second the string completes.

Related closely to frequency is the concept of pitch. When an object vibrates quickly we perceive the pitch to be higher. The opposite is true of an object that vibrates more slowly: we perceive the pitch to be lower. Pitch is a psychological, or, if you prefer, subjective term. Frequency is an objective measurement of the vibrations per second. The ear and brain, however, interpret frequencies with the psychological concept of pitch. To understand how this process works we must examine how we hear.

How Sound is Received

The mechanism of hearing consists of three parts: the outer, middle and inner ear. Figure 3.2 shows a cutaway illustration of the ear. The outer ear consists of the external parts and the ear canal which extends to the ear drum. The middle ear contains a chain of three small bones commonly referred to as the hammer, anvil and stirrup. The
THE HUMAN EAR

1. Pinna (auricle)
2. External auditory meatus
3. Tympanic membrane (eardrum)
4. Malleus (hammer)
5. Incus (anvil)
6. Stapes (stirrup)
7. Round window
8. Semicircular canals
   8a. Superior canal
   8b. Horizontal canal
   8c. Posterior canal
9. Membranous labyrinth
10. Cochlea
11. Cochlear duct
12. Acoustic nerve
   12a. Cochlear nerve
   12b. Vestibular nerve
13. Eustachian tube

from Compton's Encyclopedia and Fact-Index, Vol. 7
inner ear, which resembles a small snail shell, is filled with liquid and contains numerous small and delicate membranes, fibers and hair cells. When a sound wave reaches the outer ear it is then focused and magnified by the shape of the outer ear parts and transmitted to the ear drum. The ear drum reacts to the vibrations and causes the three small bones in the middle ear to work in tandem and transfer this energy to the oval window. These vibrations are then transferred to the liquid filled inner ear which, through a process we do not completely understand, stimulates membranes, fibers and hair cells. This stimulation is transformed to electrical impulses which are transmitted to the brain for processing. It is interesting to note that the hair cells are stimulated by about 24,000 small fibers which are sensitive to various frequencies. The brain perceives these frequencies to be particular pitches. Thus we see the difference between the physical concept of frequency and the psychological sensation of pitch.

The actual mechanism of hearing is not as important to the study as is the understanding that sound waves are what initiates hearing and that the sound waves contain elements which allow the ear to determine, among other attributes, frequency (pitch), sound pressure (loudness) and direction of the sound source.
Definitions Important to the Study

Before we examine some specific information regarding instruments and voices, it is important to have an understanding of some acoustical concepts basic to the study. There are a number of elements in acoustics that could be examined when considering the placement of musicians for performance. The focus in this study has been limited to areas which have the greatest propensity for change by positioning of the musicians.

Radiation of Sound

The first of these concepts is the radiation of sound, or the directional characteristics of the instrument or voice. The radiation of sound is simply the "process whereby energy is carried away from a vibrating source through a medium." 17 Musical instruments and voices are physical systems which radiate sound waves. Although sound—as we discussed earlier—is spherical, the initial direction of the sound, and to a degree its continued direction, is determined by the shape of the vibrating body, the area from which the sound is initially emitted, and the frequency. For instance, a sound created by a trumpet is first emitted from the bell of the instrument. The sound of the human voice is emitted from the mouth cavity. This sound

then spreads outward in all directions. However, it is important to understand that this spreading out of the sound is not uniform. Jurgen Meyer states:

most instruments do not radiate sound in all directions with the same intensity, but rather have a smaller or larger directional effect. This dependence of the radiated sound pressure on the direction is called the directional characteristic. 18

These directional characteristics change when the frequency or sound pressure changes. The way in which the sound radiates from the instrument or voice is crucial in the determination of the proper seating position for performance.

Because each (instrument and) instrumental section, according to its arrangement, radiates sound more or less strongly into the auditorium and hence can also change the timbre, acoustical aspects play an important part in the choice of seating position. Because the correct proportion between the clarity of the overall sound and the intensity of the direct sound, the first reflections, and the reverberation time is influenced by the directional characteristics of the instruments, the arrangement of the orchestra is decisive. 19

In figure 3.3 the directional characteristics of a trumpet in the vertical plane at varying frequencies is shown. Notice how the focus of the direction of the sound, or directional characteristics, changes with the frequency. All instruments and voices have directional characteristics that are specific to their physical shape and manner of vibration. Although these directional qualities can be

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19 Ibid., p. 141.
FIGURE 3.3
DIRECTIONAL CHARACTERISTICS OF THE TRUMPET

from Meyer: Acoustics and the Performance of Music
slightly altered by the individual player or singer, the general directional characteristics remain fixed and are influenced more readily by frequency.

Reflection of Sound

How sound is reflected is another concept important to the placement of musicians. Reflection of sound is simply the manner in which the direction of the sound wave is influenced by its contact with other surfaces. As the sound travels from the source to the listener it is reflected, or its direction altered and intensity changed, by the shape, mass, and materials of the surfaces which it encounters. Figure 3.4 shows examples of both simple and complex reflections of a soundwave. It is obvious that the shape of the surface determines the complexity of the reflection. In figure 3.5 we are able to visualize, in a rather simple manner, how both direct and reflected sound reach a listener from the stage performer.

The importance of reflections for both the musician and the listener cannot be overstated. Besides increasing the intensity of sounds, reflections also aid us in judging the distance of the sound source. As Pierce states:

For the same intensity of sound reaching an observer, the distance of the source is judged to be greater if the same sound comes from several loudspeakers at different distances rather than from a single speaker. If someone
FIGURE 3.4

SIMPLE AND COMPLEX SOUND WAVES

EXAMPLE 1
from Backus: The Acoustical Foundations of Music

EXAMPLE 2
from Doschek: "Room Acoustics"
The Diapason
FIGURE 3.5

REFLECTIONS FROM THE STAGE TO THE LISTENER

from Pierce: *Science of Musical Sound*
speaks to us in a room, we hear mostly direct sound if the person is close to us and mostly reflected or reverberant sound if (he/she) is far away. 20

Research shows that both musicians and listeners need strong reflections of sound for a satisfactory acoustical experience. The musicians needs quick reflections of their own, as well as their fellow-musicians, sound to assist with intonation and the synchronization of the ensemble. Delayed reflections, or the lack of proper reflections, can be disconcerting.

Early reflections between musicians greatly improve ensemble conditions . . . and (the) balance between parts in the reflections should be sought at all orchestral positions. It is clear the directivity of the instruments and cross-stage interferences due to the presence of the orchestra itself are important factors in the level at which reflections arrive. 21

What musicians require, therefore, is an environment which "gives them something back," and it is clear that quick, unhindered reflections substantially alter the musicians perception of the sound.

Reflected sound, or reverberation, is also important to audiences. Recent research shows that lateral sound, or strong reflections from the listener's left and


right, apparently cannot be overdone. They give rise to a spatial impression that has recently emerged as a most desirable quality. Denis Vaughan explains the importance of reflected sound to audiences using a subjective classification including terms such as richness, density, intimacy and clarity of sound. Richness refers to powerful multiple reflections that come from a variety of one-surface and two-surface early reflections, preferably off different materials. Density refers to the number of reflections within one second from a single impulse. According to Vaughan:

We appreciate the richness more when the initial reflections are so spaced in time not to mask each other out. Because our ears allow us to distinguish between sounds coming from above, below, before and behind us, we appreciate richness most when all four areas are fairly equally supplied with reflections. 22

He defines intimacy and clarity to be two linked qualities which are most satisfactory when the listener has the impression of being surrounded by the orchestral sound.

These (qualities) depend on the earliness and exact direction of the first reflections. In particular, early reflections of medium-high frequencies help clarity and definition. Early upper-high frequencies help intimacy and early low frequencies help 'substance' or 'weight'. 23


23 Ibid., p. 14
Absorption of Sound

The manner in which the intensity of sound is reflected to the listener and the musicians is related to the concept of absorption. "Absorption is the weakening of sound waves through incomplete reflection." 24 Sound is absorbed at different levels dependent upon the material of the surface it encounters. Hard plaster reflects a large amount of sound and absorbs very little whereas felt absorbs a large amount and reflects little. Figure 3.6 shows an example of the percentage of sound that is absorbed by varying materials. The human body is an excellent absorber of sound. This helps to explain the difference in the reverberation time in an auditorium when the hall is half, as opposed to completely full.

In our discussion of the placement of musicians, considering the already mentioned directional characteristics and need for reflections by the audience and the musicians, it is important to recognize that the absorption quality of reflecting surfaces can substantially alter the intensity of the reflections. It is recognized that it is best to have a 'live' stage, i.e. one that is relatively free of absorbing material. At the same time, it is suggested that the rear of the hall behind the audience have

<table>
<thead>
<tr>
<th>Material</th>
<th>Percentage of sound striking it which it absorbs (approx.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hard plaster</td>
<td>3%</td>
</tr>
<tr>
<td>Cotton draperies hung against wall</td>
<td>8%</td>
</tr>
<tr>
<td>Velour draperies 4 inches from wall</td>
<td>33%</td>
</tr>
<tr>
<td>Perforated metal enclosing 1½ inch thickness of mineral wool</td>
<td>74%</td>
</tr>
<tr>
<td>Open window (theoretically)</td>
<td>100%</td>
</tr>
</tbody>
</table>

from: Bartholomew: *Acoustics of Music*
some absorbing material to help reduce potentially
disturbing rear reflections. Excessive rear reflections
tend to cause echoes in the sound for both the audience and
the stage musicians.

It is possible to use the absorption ability of
varying materials on the stage to dampen certain qualities
or frequencies of selected instruments. For example,
consider the trombone. Because the trombone section usually
sits on the last row of the orchestra, it is possible to
increase the absorption of rear wall reflections from behind
the instruments with a curtain or similar absorbing
material. After investigating the directional
characteristics of the instrument, we find that the rear
wall reflections affect the sound in the room only in the
frequency region below 400 cycles.

An absorbing rear wall, therefore, causes a
decrease only of low frequencies, which leads
to a slightly lighter timbre, whereas the timbre
has more fundamental with a reflecting rear wall.
The sound intensity, (however), is hardly changed. 25

Thus, it is possible for the conductor who is knowledgeable
concerning the directional characteristics of an instrument,
the area of reflections and the absorption ability of varying
materials, to affect not only the intensity but also the
quality of sound through simple placement of the musician.

Overtones and the Formant Region

Another concept of acoustics important to the study is the understanding of the presence of partials or overtones in the production of sound. An overtone is simply a frequency that is produced when the fundamental is played. When a vibrating body, such as the violin string we discussed earlier, vibrates as a whole, the tone it produces is called its fundamental or first partial.

If it vibrates in two parts or segments, as when a string player lightly touches the string at its midpoint, the vibrating length is only half as long as is the original, and thus it vibrates twice as fast... The tone produced in this case is the octave, or second partial.

Each time the vibrating length of the string is segmented, a new partial or overtone is created. These partial tones make what is termed the harmonic series. Figure 3.7 shows the first sixteen partials of the harmonic series constructed on C two octaves below Middle C and up. It is important to understand that the harmonic series does not end with the sixteenth partial. Theoretically, it continues indefinitely — beyond the threshold of hearing.

Musical instruments and the voice produce fundamental frequencies and overtones of fundamental frequencies. The overtone structure is one of the

Harmonic series on C.

from: Bartholomew: *Acoustics of Music*
characteristics which distinguishes various voices and instruments.

the fundamental frequency is the lowest frequency component in a complex sound wave. When musicians speak of the range of a voice or musical instrument, (they) usually mean the frequency range of the fundamental frequencies which the voice or instrument is capable of producing. 27

Instruments and voices produce overtones at varying strengths depending upon their physical makeup and the fundamental.

The characteristic tone quality of an instrument is due to its relative strengthening of whatever partial lies within a fixed or relatively fixed region of the musical scale. This region is called a formant of the tone. 28

For instruments the strengthening of the partials in the formant range usually occurs through resonance of a certain part of the instrument or the enclosed body of air in the instrument. In either case it is an area that is natural, and somewhat fixed, to the particular instrument. The formant theory also helps to explain how the quality of an instrument tends to change as the fundamental pitch rises. When the fundamental reaches any formant pitch that formant drops out of the complex tone producing a simpler, and less resonant, tone.

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The important concept to bear in mind is that overtones which occur in the frequency area of 2500 to 4000 cycles are the most important to the human hearing process since they lie within the range at which the ear is most sensitive. This also explains why a listener can easily hear a trained solo singer project over an entire orchestra without amplification. Even though the total sound output of the singer can hardly match that of an orchestra, the singer can draw attention to his/her part by concentrating their acoustical power in a part of the frequency spectrum where the orchestra is not so strong. Research has shown that, in trained male singers, a large amount of energy in the region lying between 2400 and 3200 cycles is present. In female singers a similar effect is noticed at a slightly higher average point. This particular spectrum is commonly referred to as the singer’s formant. Although the amount may vary, in a trained male singer the pitch averages around 2800 cycles regardless of the fundamental pitch, the vowel sung or the type of voice. As Bartholomew states:

It would seem to be more than just coincidence that the condition of the throat that makes possible a loud, full, "round" tone production with minimum strain to the singer should produce precisely that tone which, at least during a part of its vibrato cycle, contains a large amount of energy in the relatively narrow frequency range for which his, and the listener's ear is most sensitive. 29

Singers, through training, can develop a "singing formant" throughout most, if not all, their vocal range. The singer's formant concept helps explain why one singer can project over an entire symphony orchestra. Baccus summarizes this concept stating:

The average spectrum of a symphony orchestra shows that in this frequency region (the formant region) its sound output is some twenty-five decibels below its maximum value at lower frequencies. The singing formant thus emphasizes the frequencies for which there is not much competition from the orchestra and so helps the singer's voice to stand out and not be masked by the orchestral accompaniment.

It is important to note, however, that the female singer does not have the same problems of projection as the male singer. This is because her voice is already in the frequency region where the orchestral accompaniment is deficient. However, for the high notes of the female voice, the fundamental frequencies are above the lower formant frequencies associated with the vowel speech sounds. To compensate for this, the female singer, through vowel placement and vocal cavity adjustment, can learn to move the lowest formant frequency up to match the fundamental frequency for high notes. Quite simply the female singer, unable to sing a particular vowel at a specific pitch and create the necessary formant region, instead creates the

30 Baccus, Acoustical Foundations, p. 255.
illusion of the vowel while modifying the actual vowel sound through increasing the mouth opening.

The great paradox of vowel modification is that when the modified vowel is sung (to adjust for this formant region), it will sound more like the intended vowel than will the pure vowel. 31

J. Loren Jones suggests that when the singers have their vowel formants absolutely tuned in to the proper overtones they will have attained the maximum resonance.

under these conditions (they) will have greater volume with less effort. Soft (singers) will have greater carrying power, less breath will be required to produce the same amount of tone, and (the singer) will have a tone which has beauty, brilliance and ring. Conversely, the singers who do not know how to tune in their formants will produce a weak, dull uninteresting tone, will need to use more effort to attain the forte volume level, (and) will become physically tired while singing. 32

Any definite pitch instrument, voice, or vibrating body has a particular frequency area or fundamental which produces a strengthening of the overtones in this area of hearing sensitivity. This pitch, or group of pitches, is referred to as the instrument's formant region.

The conductor can generally do very little to enhance the ability of an instrument to strengthen overtones in the formant region since they are, in the main, a natural


resonant characteristic of the instrument. They can, however, work with singers to increase their ability to produce a fixed formant throughout their vocal range. The chorus's ability to continually sing in this manner will enhance their ability to project over instruments. Stephen Bolster points out the importance of this quality when he states:

Some conductors believe that the ring of the singer's formant in the individual voices of a choir precludes the achievement of an acceptable blend. Yet the "2800" ring is exactly the resonance that is needed by a choir to project over instrumental accompaniment, especially that of large symphony orchestras. 33

Chapter IV
Architectural Considerations

Another element critical in the arrangement of musicians for performance concerns the architectural design of the performance location. Generally, conductors have little choice concerning the performance location for large choral/orchestral works and little, if any, opportunity to change the basic architecture of the space. With some general knowledge of architectural acoustics they do, however, have the opportunity to place the musicians in such a manner as to highlight the good acoustical qualities of the hall and lessen the unfavorable elements. They must first beware of basing their impression of the acoustical quality of a hall on their visual perception.

An experienced ear will separate the good from the bad, which the eye does not. Therein lies a common danger. There are more than a few musicians and music lovers whose perception is influenced, if not dominated, by what they see rather than what they hear. 34

To form a knowledgeable opinion, and make good decisions concerning the placement of the musicians, some basic information concerning what kind of architectural designs and elements provide a good acoustical environment is necessary.

Michael Forsyth, in his book *Buildings for Music*, discusses some of the important characteristics of the architecture of a building relative to acoustics and the performance of music. He indicates that rectangular halls have several important positive acoustical characteristics. One of these is a relatively small seating area. This gives the acoustic advantage of intimacy, that is, no sections of the audience are extremely distant from the sound source. He also notes the positive effect of high ceilings in most rectangular halls. High ceilings tend to provide a large volume relative to the seating area. This ratio is significant, as the clothed human body is highly sound-absorptive in the medium-to-high frequency range. The width of a building's structure also contributes to its acoustical qualities.

The generally narrow width of a rectangular hall helps ensure that no member of the audience is far from a side wall. This means that each listener receives powerful lateral sound reflections soon after the direct sound. This combination of quick lateral reflections and good direct sound gives the music good definition and makes it seem to fill the space when the musicians play at forte. 35

These are similar to the principles which were observed and commented on at length by Leo Beranek in his book *Music*.

Acoustics and Architecture written in 1962. Beranek made a comparison of fifty-four performance halls in varying locations and attempted to explain acoustically what made them either 'good' or bad halls. He found that a rectangular shaped hall frequently produced a good acoustical environment. He attributed much of this to the width of the hall and the type of side reflections enhanced by its design. For example, he blamed the thirty-four meter width of Salzburg's Grosses Festspielhaus for its "harsh" and "modern" sound and compared the hall's width with the sixteen meters between balcony faces in Philadelphia's Academy of Music, which produced a "soft, 1860 sound."

Another architectural element important to acoustics is the inclusion of balconies and/or irregular surfaces on the side walls of the hall. Balconies enable the sound to reflect off the side walls onto the ceiling. Irregular surfaces increase the complexity and diversity of the directional characteristics of the reflections. Without balconies, or some irregular surfaces, the side wall reflections would travel in too uniform a direction and simply pass over the heads of the audience.

Although balconies and surfaces may play an influential role in the acoustics of the hall, the outer contours, or main boundaries, are of most importance. Siegmund Levarie suggests:

acoustically, shapes may be divided into two classes: those that are on the safe, favorable side; and those that are on the risky, unfavorable side. To the former belong
the classic rectangular shapes with flat roofs. to the latter belong all those shapes that exhibit curved surfaces, which are likely to produce sound echoes. 36

A rectangular hall outfitted with balconies, irregular surfaces, and a high ceiling are not all, however, that is needed for a good acoustical environment. As Forsyth states:

there are enough poor rectangular halls in existence, together with renowned halls that do not conform to a rectangular shape, to show that other factors are also involved in determining acoustic excellence, mainly the room’s construction and the materials from which they are built. 37

Thus, the materials used to construct both the external and internal area of a hall are critical to the acoustical quality of the building.

One unfounded belief concerning construction material has been that the tinest halls are predominantly built of wood, and that the surfaces resonate and reinforce the sound like a violin. In reality, resonant paneling only absorbs sound energy and weakens its loudness and reverberance. The analogy with the musical instrument is false: the sound energy generated in a massively constructed concert hall, compared with that in a violin made of very


thin wood, when one takes into account the relative size, is extremely slight. The attributes of string reverberance and a full bodied bass tone actually depend, given adequate volume, on hard rigid surfaces that reflect the sound produced.

Although conductors cannot always choose the concert site, they can keep these and other architectural acoustical elements in mind. Furthermore, once the conductor realizes the importance of strong, quick side reflections reaching the listener prior to ceiling reflections, and to what extent kinds of material absorb sound intensity, it is easier to visually assess the possible acoustic qualities of most halls. More importantly, they can focus on the important characteristics of sound radiation, reflection and absorption when examining the architectural design of the hall to determine proper placement of personnel. The placement of musicians with regard to their directional characteristics, with consideration of the design of the hall, will help to enhance the reflection of the sound to the audience and other musicians. The placement with regard to the absorption by construction material and other elements, including other musicians, helps to ensure that the sound is radiated freely to the reflecting surfaces. Knowledge of the absorption qualities of the reflecting surfaces helps the conductor ascertain how the sound will be received by the audience and musicians prior to actual rehearsal or performance in the hall. An examination of key
elements in each of these areas will help the conductor design a seating arrangement that takes full advantage of the acoustical properties of the hall.
Chapter V

Acoustical Properties of Instruments

Limitations of Discussion

The research on the acoustical properties of instruments is substantial, complicated, and specific to particular areas. It would not be practical for the purposes of this study to examine the acoustical properties of each instrument of the orchestra in detail. We are instead concerned with two principal areas: 1) a basic understanding of how the instruments create sound and 2) acoustical properties of the instrument that can be altered by its physical position on the stage. In this second area we will limit the discussion to the directional characteristics of the instrument and the effect of reflecting surfaces on the instrument's radiation of sound. In this section the basic acoustical concepts of each instrument group is first briefly discussed. This is immediately followed by a more specific discussion of selected instruments within that instrument group. A sizeable amount of material for this portion of the study, particularly concerning directional characteristics and reflections, comes from Jurgen Meyer's exhaustive study of the acoustics of instruments.
**String Instruments**

The most common instruments in the string family are quite simply a set of strings mounted on a wooden box which contains an almost closed air space. Sound is produced from the vibrations induced by drawing a bow across the strings. These vibrations are communicated to the box and the air space which, in turn, sets up corresponding vibrations. These vibrations produce the sound waves that reach the listener's ear.

The vibration of the moving string without a resonant box would produce an almost inaudible amount of sound. It simply has too little surface area to set an appreciable amount of air in motion. As Carleen Hutchins explains:

_What happens is that some portion of the energy supplied by the player to the bow -- perhaps five to ten percent -- is communicated to the wooden body of the instrument through the complex motions of the bridge. Of all the energy that the player feeds into the violin, one or two percent emerges in sound. The rest goes off as heat. The vibrations of the bowed string at any instant includes dozens of energetic harmonics with amplitudes falling off as frequency increases. Each of the frequencies present shakes the wooden box -- "forces" it to vibrate -- at a particular rate._

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Violin

The directional characteristics of violins are some of the most complex, other than the horn. Figure 5.1 shows a simplistic example of the directional characteristics in the horizontal plane. In this example we see that the directional characteristics in the 1000 - 1250 cycle range are preferentially toward the right. This is of particular interest since this frequency region is most responsible for a clear and powerful timbre. Higher frequencies are radiated upwards, and thus their reflection to the listener is greatly influenced by ceiling reflections. These ceiling reflections are weakened and reach the audience with little intensity if the stage is too high. A lower stage allows more of the high frequencies to reach the front rows of the audience.

Rear reflections also play an important role in the radiation of sound to the audience. Meyer suggests that, when performing in rooms with high ceilings, it is helpful to keep the distance from the rear wall as small as possible, or at least less than the height of the ceiling above the audience. He states:

How the (sound) reaches the listener depends not only on the direct sound radiation but also on the reflections from the rear wall of the platform and the adjoining wall of the ceiling. Reflections from the rear of the stage
FIGURE 5.1
VIOLIN: DIRECTIONAL CHARACTERISTICS IN THE HORIZONTAL PLANE

from: Meyer, Acoustics and the Performance of Music
are of particular importance for frequencies in the 500 - 700 cycle range as well as between 1500 and 2000 cycles. 38

Viola

For the viola the frequencies in and around 1000 cycles are the most important. These are in the region that is primarily responsible for the character of the sound and some bright coloring. The sound, at this frequency level, is directed preferentially to the players right. The viola, like the violin, depends on strong rear wall and ceiling reflections. Violas share the same concerns as violins when considering the height of the ceiling in relationship to the distance of the player to the rear wall. From a tonal aspect the most favorable seating position for the viola is to the conductor's left. This allows the sound to radiate freely toward the audience. This seating arrangement is, of course, usually only possible when the composition does not call for violins.

Cello

Figure 5.2 shows the main radiation regions of the cello for the horizontal and vertical planes. Ceiling reflections play an important role in the tone quality of the instrument. This is because the regions of especially

38 Meyer, Acoustics, p. 144
FIGURE 5.2

CELLO: MAIN RADIATION REGIONS

Vertical Plane

Horizontal Plane

from Meyer: Acoustics and the Performance of Music
strong intensity reach the ceiling of the room for all frequencies. We can also note that for frequencies around 200 cycles, and in the 350 - 500 cycle range, the sound is radiated mainly towards the front and downward. Reflections off of the floor are critical for these frequencies. In the main, however, it is the ceiling reflections which are most important to the cello. This is because from 800 cycles upward the directional characteristics of the sound become so steeply inclined that they no longer radiate well towards the audience.

The question of whether the celli should be placed in the front or to the right of the conductor has a considerable impact in determining the quality of the sound. As Meyer states:

(In a forward facing position) the high frequencies (above 2000 cycles), which are an important contribution to the articulation of fast passages, are radiated into the hall (advantageously). Also the frequency region of 350 - 600 cycles, which contributes greatly to the sonority of the sound, radiates better in this position. 39

He indicates that an arrangement to the conductor’s side produces an increase in the radiation of the frequencies which give the cello a darker tone. In this side position

the important frequencies around 400 cycles are greatly weakened and impaired sonority results. Overall it would seem a forward facing position would be most advantageous for the tonal quality of the instrument.

**Double Bass**

When the double basses are positioned either to the left or right side of the orchestra there is a change of radiation directed toward the audience of around ninety degrees. This can be noted in figure 5.3, which shows the directional characteristics of the double bass in the horizontal plane. We can also see how reflections from the rear wall intensity the sound of the double basses in the frequency region of 200 - 250 cycles, as well as between 500 - 800 cycles. For higher frequencies, direct radiation with the instrument placed on the left side is at a slight advantage. However, the higher frequency components are normally not very important since they are frequently doubled by either the cellos or the bassoons.

In these cases the overall sound is completed by these instruments rich in overtones (which) nearly always play an octave higher. However, good possibilities for radiating in the entire double bass spectrum are important in passages where there is no help from other instruments. 40

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DOUBLE BASS: DIRECTIONAL CHARACTERISTICS IN THE HORIZONTAL PLANE

from Meyer: *Acoustics and the Performance of Music*
When, on the other hand, the double basses are arranged in the front of the stage there is a significant loss of high frequency and a smaller loss of the intensity of the lower frequencies in the direct sound. This drop of lower frequencies can be problematic, since these frequencies are already weakly propagated to the audience.

**Woodwind Instruments**

All woodwinds may be disassembled mentally into three essential parts: the reed, the bore and the side holes. Air blown into the instrument through the reed sets up vibrations in the column of air within the bore, and the vibrating air column produces the sound of the instrument. The frequency at which the air vibrates is determined chiefly by the dimensions of the bore. These dimensions are modified in turn by the side holes in both their open and closed positions. 41

These elements are true of all woodwind instruments. In the case of the flute, the function of the reed is served by a thin jet, or "reed," of air blown across the mouth hole. Each woodwind instrument has natural modes of vibration which depend chiefly on the length and shape of the bore. The lowest, or fundamental, frequency of vibration is a sound which has a wave length twice the length of the bore. They can also vibrate in higher modes which are directly tied to the harmonic series. In reality, woodwinds

make extensive use of only the lowest three or four of their natural resonating modes. The lowest mode corresponds to the so-called low register, the second mode to the middle register and the upper register uses one or another of the higher modes.

It is important to note that a woodwind produces the lower components of its tone rather inefficiently with only the first one or two holes open. In higher frequencies, however, the sound is radiated more efficiently -- although it is highly directional -- since all the open holes can act together. The sound actually radiates from a row of open holes. The addition of the bell simply reflects efforts over the years to provide the bore with a radiating system that approximates the behavior of a row of open holes even when all the holes are closed. In contrast to the clarinet, oboe and bassoon, the flute and saxophone radiate all components of their tones as it from a single hole.

Flute

The directions of radiation for the flute are rather complex since it depends on both the frequency and the ordinal number of the harmonics. Figure 5.4 shows the main directions of radiation for the flute. We see that the sound is strongly radiated to the front over a wide angle for most frequencies.

Only the highest frequencies are preferentially radiated to the right and all the other components
FIGURE 5.4
FLUTE: MAIN DIRECTIONS OF RADIATION

from: Meyer: Acoustics and the Performance of Music
are weaker in this direction than to the player's front. Because the highest frequencies usually are at high dynamic levels, the fortoe can acquire a slightly disagreeable sharpness. 42

The usual placing of the flutes on stage is seen to be acoustically favorable if the player faces the audience. Free radiation to the front is advisable as well as good ceiling and rear wall reflections. The rear wall reflections are particularly important for lower frequencies. They help to increase the sound intensity and support a round tone. Ceiling reflections are important since it is the primary direction of strong radiation from the instrument.

Clarinet

Oboes and clarinets are quite similar in the region of greatest radiation of sound. When the performer sits facing the listener the important frequencies around 1000 cycles are radiated directly to the audience very advantageously. Ceiling and floor reflections play an important role, especially in conjunction with free radiation toward the front without pronounced obstruction by other musicians. Reflections from the rear wall have only slight implications for the sound. Due to specific acoustical qualities of the instrument, the floor

42 Meyer, Acoustics, p. 152.
Reflections have a major impact on the tone. Floor reflections, especially at higher frequencies, can cause the tone of the clarinet to become brittle and sharp. Because of the absorption of high frequencies in the hall, this effect does not arise with equal distinctiveness for all listeners, but when recording oboes and clarinets with microphones it will be seen that relatively small changes of position, and hence a slightly different angle of radiation, can cause a noticeable change in the overall sound for the various high frequencies. 43

Oboe

As mentioned earlier, the clarinet and the oboe share many similar directional characteristics. In figure 5.5 we see the directional characteristics of the oboe at varying frequencies. We can see that frequencies in the region of the main formant of the oboe, about 1000 cycles, are radiated forwards into the hall advantageously. Direct sound radiation at 2000 cycles also takes place in a horizontal and slightly upward direction toward the listener. Reflections from the ceiling, however, depend very much on the ceiling slope. If the ceiling is horizontal, the reflection in the main, comes back to the orchestra. If, however, there are slanted reflectors, a reflection of sound towards the audience is also possible. For the higher

FIGURE 5.5

DIRECTIONAL CHARACTERISTICS OF THE OBOE

from Meyer: Acoustics and the Performance of Music
frequencies the radiation of sound is preferentially towards the floor. This means that the intensity which reaches the listener is very much a function of the reflecting ability of the floor covering. Within the orchestra these frequencies are also rather strongly absorbed by the musicians sitting in front of the oboe. This inevitable weakening of the highest frequencies is, however, felt to be pleasing from an aesthetic point of view because the tone of the oboe otherwise becomes too shrill and sharp. The increased obscuring of the rear directional characteristics by the player himself only affects the sound when there are rear seats for the audience. This means that it is not really important to have a reflecting wall behind the player. Unhindered propagation of sound to the front and upwards is most important for a good development of tone.

Bassoon

The bassoon's directional characteristics are quite different from other woodwind instruments. This is due primarily to the size of the instrument and the upward playing position. Figure 5.6 shows the main direction of radiation for the instrument. We can see how in most frequencies the sound is radiated preferentially toward the front and rear. The importance of rear wall and side wall reflections can be noticed in the frequencies around 300 cycles. Floor reflections also play a major role in the frequencies around 500 cycles, the area of strongest
FIGURE 5.6
BASSOON: MAIN DIRECTIONS OF RADIATION

from Meyer: Acoustics and the Performance of Music
components for the instrument. In the main the sound is
directed straight toward the audience, but some sound
reaches the listener from side wall reflections.

The disposition of the preferential radiation
into four beams in the neighboring frequency
region beyond 1000 cycles causes strong reflec-
tions from the ceiling and rear walls. Some parts
are directed to the audience, if the rows of seats
rise sufficiently steeply, but with a flat platform
these components can only reach the audience through
reflections, and therefore they will be a little
weaker in the whole. The bassoon tone thereby loses
a little of its power and brightness. 44

**Brass Instruments**

The essential elements of a brass instrument
consist of a mouthpiece, a mouthpipe, a main bore and a
flaring bell that forms the exit from the interior of the
instrument to the outside space. Brass instruments can be
divided into two families. This first family, represented by
such instruments as the trumpet, trombone and the French
horn, have a considerable length of cylindrical tubing in
the middle section and an abruptly flaring bell. The other
family, called conical, includes instruments such as the
flugelhorn, the alto horn and the tuba. Conical refers to
the fact that much of the tubing increases in diameter from

the mouthpiece to the bell. The bell of the instrument, in most cases, is less pronounced than the instruments in the first family.

In a brass instrument the small end of the horn is connected to the player through his lips, which constitute a kind of automatic controlled valve for admitting air from the player’s lungs to the horn. The opening and closing of the valve is controlled chiefly by the pressure fluctuations within the mouthpiece as they act on the lips in concert with the steady pressure from the lungs. 45

When a player creates a sound wave through the instrument it travels down the length of the bore losing some of its energy by friction. At the end of the horn, the bell reflects back toward the mouthpiece a substantial fraction of this wave. The remainder of the sound is radiated out from the bell into the surrounding space.

One of the more interesting acoustical aspects of brass instruments is their natural ability to transform the internal spectrum of the sound to an external spectrum that has the general nature of a treble boost. In other words, no matter what kind of sounds are generated inside the instrument it is the higher components that are radiated into the hall. This helps to explain why trumpets, which have a greater tendency to emit higher component sounds than other instruments, seem to cut through the sound of an orchestral ensemble so easily.

Trumpet

Figure 5.7 shows the main directions of radiated sound for the trumpet in the horizontal plane. The radiation of sound remains rather uniform for frequencies up to 500 cycles. For frequencies beyond that level however, we notice a concentration toward the front in a semicircular shape. For these frequencies reflections from the ceiling and side walls are important for the listener. Notice that sounds around 800 cycles have a tendency to increase direction in both a backwards and sideways fashion. Ceiling, side, and rear wall reflections are extremely important for this frequency level. We see an increased focusing of the sound toward the front of the player as the frequency level rises to around 1000 cycles and upwards. At these frequencies, reflections from remote parts of the ceiling and side walls become important for projection of the sound to the listener. This is particularly important because this is the frequency region wherein the trumpet's strongest components lie. It is these components that give the instrument its unique timbre.

The fact that the reflections from the rear and side walls of the platform are only important for the lower frequencies is especially obvious when compositions involving a large choir are performed. The timbre of the trumpet on the whole is preserved in the hall whereas most of the other instruments are adversely affected in intensity, and especially in brilliancy, by the effects of absorption by the choral singers. 46

46 Meyer, Acoustics, p. 166
FIGURE 5.7
TRUMPET: DIRECTIONAL CHARACTERISTICS IN THE HORIZONTAL PLANE

(from Meyer: Acoustics and the Performance of Music)
The sound radiation of the trombone is similar to that of the trumpet, at least for frequencies below 1100 cycles. In these lower frequencies the main sound is directed preferentially toward the front. We can, however, expect strong absorption of components directed to the floor by the musicians sitting in front of the players. Unlike the trumpet, side wall reflections are very important for the trombone for frequencies below 1100 cycles. At these frequency levels the intensity of sound radiated to the sides is almost as strong as that radiated toward the front. This quality is also, in effect, what gives the trombone its sonority. Some conductors even arrange the trombones on the concert platform so that they "play at right angles towards the middle instead of playing directly into the hall because then their tone can amalgamate better." 47 This is understood to mean that the trombones join into a chord by a more inconspicuous entry. It does not mean playing with any less intensity of sound. The conductor should note that, because of the directional characteristics, the higher frequencies reach the player's ears relatively weakly. All

the player can perceive is an intensification of these components by the rear wall reflections. Occasionally this results in the musician playing more softly and thus, the tonal effect in the hall is weakened.

Tuba

Figure 5.8 shows the main directions of radiation for the tuba. Notice how, similar to a trumpet, the direction of the sound becomes extremely focused as the frequency level increases. The direct sound from the instrument to the audience is only important in the lowest frequency region. This is because in the lower register overtones of frequencies at a high level appear. This can make the sound itself conspicuous if the higher frequency components reach the audience with too much strength due to unfavorable reflecting areas.

Since the reflecting surfaces of the orchestra are very important to most of the other instruments, it follows from this consideration that the tuba usually has to adapt his dynamics to the presence of reflectors, and a higher dynamic level than mezzoforte should not be blown so as to achieve a full and tranquil sound. 48

Horn

The directional characteristics of the horn are the most complex of any of the instruments in the orchestra. Figure 5.9 shows the main directions of radiation in the

FIGURE 5.8
TUBA: MAIN DIRECTIONS OF RADIATION

from Meyer: Acoustics and the Performance of Music
FIGURE 5.9
HORN: DIRECTIONAL CHARACTERISTICS IN THE HORIZONTAL PLANE

from Meyer: Acoustics and the Performance of Music
horizontal plane. Figure 5.10 shows the directional characteristics in the vertical plane. We can see that in the horizontal plane frequencies between 150 and 250 cycles, as well as between 300 and 500 cycles, are radiated over an area resembling a semicircle. As the frequencies rise the directivity narrows and is emitted preferentially to the players right. Thus, these components will reach the listener primarily through side wall reflections. In the vertical plane we see that as the frequencies rise the focus shows a concentration upward. Thus, ceiling reflections also play a major role in reflecting the sound to the listener. The playing dynamics are more effective if the higher frequencies, which only appear with increasing sound intensity, are directed advantageously to the audience. If not, the forte can remain weak in character.

Rear wall reflections are, of course, very important to the tone of the horn. The horn sound gains in intensity by the reflecting effect of the rear wall; the lower region of the components is intensified the least, and the brightening components of the region of the vowel color "e" which form a characteristic subsidiary formant for all the usual horns are especially favored. 49

**Percussion Instruments**

There is not sufficient space, or need, in this document to cover all the directional characteristics of instruments within the percussion section. Basically, the

FIGURE 5.10

HORN: DIRECTIONAL CHARACTERISTICS IN THE VERTICAL PLANE

from Meyer: Acoustics and the Performance of Music
instruments of the percussion section fall into two categories: 1) those with definite pitch and 2) non-definite pitched instruments. Definite pitched instruments would include instruments such as the timpani, marimba, and xylophone. Non-definite pitched instruments would include instruments such as the snare drum, gong, triangle, and wood blocks. It would not be of much use for the conductor to consider the directivity of all the instruments in the percussion section. This is because in a typical work their placement is determined primarily by space and the player's needs. The placement of the timpani is most flexible. Some conductors prefer to have the timpani in the center of the orchestra, others arrange the timpani either with the rest of the percussion section or, occasionally, near the double basses. The overall placement of this section is determined by the composition, space and the individual player's needs. In addition, it would be difficult to easily consider the directional characteristics of such instruments since "the tones are highly transient and die out quickly after being produced. Most tones of percussion instruments are not periodic (i.e. systematic, reoccurring vibrations) and their partials are not harmonic."

Chapter VI

Acoustical Properties of Voices

The acoustical properties of the voice are determined, to a large degree, by individual characteristics of the singer. The singers' physical makeup, including their natural ability to resonate, and their professional training influence the acoustical qualities of the voice. Some generalities concerning vocal acoustics, however, apply to all singers. We again want to focus on the concepts of radiation of sound and the importance of reflections upon the sound for the purposes of this study.

Radiation and Reflection

In figure 6.1 we see the directional characteristics of the human voice in both a horizontal and vertical plane passing through the mouth for the frequencies 100, 400, 1000, 4000, and 10,000 cycles. Example A is the horizontal plane. Example B is the vertical. As you can see, there is very little frequency discrimination over a total angle of ninety degrees in the forward direction. However, beyond this angular range there is a considerable loss of high frequency radiation. Simply put, as the frequency rises, the directional characteristics become more narrow. The vertical plane is of particular interest. As the frequency level rises the sound becomes focused in a more upward direction and radiation towards the floor and sides
FIGURE 6.1
DIRECTIONAL CHARACTERISTICS OF THE VOICE

The directional characteristics of the human voice in a horizontal plane passing through the mouth for five different frequencies. (After Dunn and Farnsworth.)

The directional characteristics of the human voice in a bilaterally symmetrical vertical plane passing through the mouth for five different frequencies. (After Dunn and Farnsworth.)

from Dunn and Farnsworth: Journal of the Acoustical Society of America
decreases. These characteristics help to emphasize the importance of ceiling and side wall reflections for the singers. This would indicate a need to avoid placing the singers under an extremely high ceiling, such as a dome-like structure, or a close overhang. In the former, the length of time it takes for the ceiling reflections to return to the singer becomes a problem for the singer's internal feedback system and the ensemble of the group. In the latter, the ceiling reflections occur too soon and, depending upon the angle of the ceiling slope, can be driven immediately to the floor. Both these situations deprive the singer and listener of properly reflected sound. Singers require a good proportion of both direct and reflected sound. Lack of properly reflected sound to the singer disturbs the cohesiveness of the ensemble.

Masking of Tones

Masking of tones is another acoustical phenomenon important to the acoustical properties of the choral ensemble. Masking is the result of a louder sound drowning out a softer sound. The closer the tones are in frequency, the more easily one sound is masked by the other. The louder tone causes the softer tone to become inaudible, even though the softer tone is well within the normal threshold of hearing. Robert Trainer, in a 1986 lecture recital, discusses problems presented by masking for the choral
ensemble. He indicates that men's voices have a greater effect on women's voices due to the fact that lower frequencies will mask higher frequencies more effectively. He indicates that "if the women stand in front of the men the female voices will be masked by the men whereas if the women stand behind the men the women's voices will not be masked." 51 The best arrangement, from an acoustical point of view, according to Trainer and others is a mixed formation. This is due to two important factors. First, a mixed formation helps to reduce the problem of masking; and second, the need for the singers in a choral ensemble to receive a good amount of direct sound from all voice parts is addressed.

Turning back to masking, we find that increased space between the singers and an alternation of men's and women's voices in the formation helps to dampen this effect. The space between the singers, however, must not be too large. This relates to the second point; the singers' need for direct sound. As the singers produce their own sounds they are constantly evaluating their production to others in the ensemble. Therefore, they need to be close enough to others to receive information on the entire ensemble sound. This allows them to adjust their own production as

necessary. A mixed formation is particularly beneficial to the singers since it allows them to relate to all the voice parts rather than just to their own section. From an acoustical point of view, a mixed formation with a distance of twenty-four to forty-eight inches between singers is considered ideal to overcome these two effects. Psychologically this distance also allows the singer to produce the sound with more freedom — in a more soloistic manner. This means, with trained singers, that there is more possibility that they will be able to each individually achieve the singer's formant discussed earlier. This, of course, enhances the ability of the chorus to project over the orchestral forces.
Chapter VII

The Model Choral/Orchestral Seating Arrangement

Adaptation and Limitations of Space

My goal in this study has been to provide foundational knowledge on acoustics toward the development of a well-balanced seating arrangement which can be easily adapted to a variety of spaces. Creating a seating arrangement that could not be utilized in other halls due to varying space and logistical concerns would not be helpful. Considering acoustical concepts which are too specific to a particular hall would not allow the study to be of practical use for other choral conductors. With that in mind, I will now discuss how, utilizing the acoustical concepts in the study, I planned the seating arrangement for Trinity Presbyterian Church in Tucson, Arizona. In doing so I had to consider two important limitations: 1) the physical space of the hall, and 2) the need for ensemble between the musicians. First, let us look at the basic acoustical qualities of the hall for which the seating arrangement was designed.

Architectural Considerations

Trinity Presbyterian Church is a large church, seating roughly one thousand people, which was built in the
late 1950s. It is rectangular in shape with a relatively wide width across the inside hall. The building is constructed of brick and has very little carpeting in the main hall. A large balcony is located at the rear of the hall with tiered seating. The partition which separates the foyer from the main sanctuary is aligned at a ninety degree angle with the balcony. Because of this, there is no overhang underneath the balcony in the main seating area. The partition that separates the main hall from the foyer is constructed primarily of glass.

The front area of the church is comprised of a stepped chancel, two lecterns positioned at either side, and a three-tiered choir loft. The loft is semicircular in design and can comfortably seat seventy singers. The entire chancel and loft area is covered with carpeting.

The sides of the hall are quite different from each other. There is a jagged configuration on the left side wall which has three exit doors built into its design. Although the doors are constructed of glass, the primary construction material of the side wall is brick. The right side of the hall has a lowered ceiling overhang supported by three relatively small pillars. This lowered ceiling juts into the main hall approximately six feet.

The hall has a relatively high ceiling which is shaped into an inverted "V." That is to say that the ceiling gently slopes to both sides from the middle of the hall. The seating area for the congregation contains solid, hardwood
benches. Most of these do not have any kind of padding or upholstery. The same is true of the choir loft. There is a small strip of carpeting which extends down the center of the main hall dividing the sanctuary into two major seating areas. The choir loft and chancel, as mentioned before, are completely carpeted. Wood is the primary construction material in the altar area.

In terms of height, the chancel is twenty-four inches above the floor of the main hall. The choir loft has two tiered levels which each rise in twelve inch increments. The main focal point of the front of the church is a large cross and heavy drapery positioned directly in the middle of the choir loft on the rear wall. The drapery extends from the top tier of the loft to the top of the ceiling. It is relatively narrow in width.

Adaptation of the Space for Performance

To create the physical space necessary for the orchestra and choir, three slight adaptations of the space were made. First, the benches in the loft were removed and placed to the sides of the main hall. This space was then slightly modified by creating flat, level surfaces at the height of the top tier on both the left and right sides of the loft.

Second, a large stage constructed entirely of pine wood was built to extend, and level, the chancel. This stage, twenty-four inches in height, extended the chancel
eighteen feet toward the audience. The width of the stage corresponded to the distance of the original chancel between the two lecterns. The first two rows of pews in the main sanctuary were removed to accommodate the stage.

The third change involved building two-tier platforming on the immediate left and right of the newly constructed stage. These platforms extended to within six feet of either side wall of the hall. The tiers were built at twenty-four and sixteen inch heights. Although it would have been preferable to build the platforms on the sides to a higher level, the platforms needed to achieve this goal were not available.

**Demonstration Composition**

The composition utilized to demonstrate this arrangement of musicians based on acoustical principles was Andrew Lloyd Webber's *Requiem*. Figure 7.1 shows the instrumentation for the composition. In general, it is scored for the kind of instruments typically found in most large choral/orchestral compositions. There are, however, two notable exceptions. First, unlike most works, it does not call for violins in the instrumentation. Occasional parts that might be normally given to the violins are scored for synthesizer. The synthesizer, however, is not simply a substitution for the violin. Instead, it is an integral instrument in the composition. It is frequently called upon to provide a variety of sounds.
FIGURE 7.1

ANDREW LLOYD WEBBER

REQUIEM

for
Soprano, Tenor, Treble, Chorus
and
Orchestra

Orchestration

Violas
Cellos
Basses
Flute 1 (doubling Alto Flute)
Flute 2 (doubling Piccolo & Alto Flute)
Oboe 1 (doubling Oboe D'amore)
Oboe 2 (doubling Cor Anglais)
Clarinet 1 (doubling E flat Clarinet)
Clarinet 2 (doubling Bass Clarinet)
Saxophone 1 (doubling Soprano, Tenor & Alto Flute)
Saxophone 2 (doubling Alto, Baritone & Clarinet)
2 Bassoons
Contra Bassoon
4 Horns
3 Trumpets
4 Trombones
Timpani
Harp
Piano (doubling Celesta)
Synthesizer (DX7)
Organ

PERCUSSION: 4 Players (including Kit)
Side Drum
Bass Drum
Cymbals
Triangle
Small Suspended Cymbal
Medium Suspended Cymbal
Large Suspended Cymbal
Deep Suspended Cymbal
Tambourine
Deep Military Side Drum
Small Ratchet Rattle
Glockenspiel
Xylophone
Gong
Large Gong
Small Bell
Bells
Tubular Bells
Bell Tree
Wood Block
Congas
Maracas
Marimba
High Roto Tom
Kit
Second, the composition includes saxophones in the orchestration. Although the inclusion of saxophones into the orchestral sound is not typical, it is not exceedingly rare in twentieth-century compositions. For example, Ravel uses this instrument in his Boléro and Milhaud in his The Creation of the Earth.

The Orchestra Seating Arrangement

The orchestra was seated on the stage extending from the altar, the remaining altar area, and the choir loft. To accommodate placement of the orchestra in the loft, the choir pews were removed. When creating the seating arrangement, one of the elements of prime importance was the need to balance the demands of the acoustical requirements with the physical space needed for the orchestra. A few of the instruments were positioned primarily based on space, rather than acoustical, concerns. These instruments included the percussion section (including the timpani), the piano, the organ console, the synthesizer, and the harp.

The organ console is permanently positioned in the middle of the chancel facing the main seating area of the sanctuary. Moving this instrument was not possible, nor considered. The percussion section, due to the large number of instruments called for in the composition, needed a large, level area from which to play. Although, for acoustical reasons, it might be preferable to locate the percussion section in another area, the sheer number of
instruments and players made an ideal acoustical location an impossibility. They simply had to be located in a space large enough to accommodate the instruments and allow the players room to move from one instrument to another. With these considerations in mind, the percussion section, excluding the timpani, was positioned in the left rear area of the choir loft. This area was leveled to a height equal to the highest tier level in the loft. This height allowed for good projection of sound and appropriate eye contact with the conductor. The timpani, like the percussion section, were placed primarily according to space needs. Although it would have been possible to place them with the rest of the percussion section, I chose to position the timpani in the back right area of the choir loft. An area large enough to accommodate the instruments was leveled off at the highest tier level of the choir loft on this side. I felt that the placing of the timpani and percussion on both sides of the loft would help accomplish two further goals. First, it would "sandwich" the main body of the orchestra between the two principal rhythmical sections, helping to establish a cohesiveness in the ensemble, particularly in highly rhythmical sections. Second, this position would provide good rear and side wall reflecting surfaces for the timpani, allowing projection without disturbing other sections sensitive to its resonance.

The harp was placed on the extended stage area on the right side near to the audience. This was to help with
the projection of the instrument as well as to provide close contact with the soloists. The interplay between the harp and the soloists, particularly the treble soloist, was extremely important since the scoring during extended solo passages was sparse and usually relied heavily on the harp for accompaniment. The height of the instrument and the possibility of obscuring the visibility of the other musicians was also considered in the final positioning.

Placement of the String Section

Since the composition chosen to demonstrate the seating arrangement did not include violins in the scoring, I was able to place the violas and cellos in a more advantageous acoustical position. The string section, as a whole, was positioned at the front of the stage. The strings were positioned as follows: the violas were placed to the conductor's left; the cellos in a forward seating position immediately in front of the conductor; and the double basses to the conductor's right slanted at a forty-five degree angle. These positions took into account several positive acoustical qualities.

First, placement of the violas in this position allowed the instruments' main radiation of sound, to the player's right, to be pointed directly toward the audience. This aided in projection of the instrument since the violas, of all the strings, have the least penetrating power. Second, this arrangement placed the cellos in the most
advantageous position for direct radiation of sound to the audience. This position, as discussed earlier, also contributes greatly to the sonority of the sound which radiates much better to the front than to the sides.

The double basses, on the other hand, presented some logistical and acoustical difficulties. Acoustically, it would have been preferable to place the double basses close to a rear-wall reflecting surface. This would have helped to enhance the intensity of the sound, particularly in the lower frequencies. Unfortunately, the need for ensemble between the string instruments had to take precedence. The double basses were placed close to the cellos to the conductor’s right. This allowed for good contact between the cellos and double basses in their frequent doubling of parts. The double basses were slanted at a forty-five degree angle to help compensate for the loss of low frequencies. Since the stage on which the strings were positioned was, in essence, a large wooden box with ample resonanting capabilities (due to the large volume of enclosed air space under the stage), the numerical strength of the string section was reduced. This, however, was not the case for the double basses which, relative to the numerical balance in the other string sections, was increased. This was done to help compensate for the loss of low frequencies due to their less than advantageous placement.
Placement of the Woodwind Section

The different angles of the principal radiation regions of each woodwind instrument and the different effects of wall and ceiling reflections combined to make placement of this section one of the most complicated. Different intensity conditions found in the directional characteristics played an important role in the placement. For example, the bassoon is prominent when located in a position where wall and ceiling reflections play an important role in creating the overall sound in the room. On the other hand, the oboe is heard best when the direct sound is allowed to arrive unhindered and where it will not be weakened on the way by other musicians. Ceiling, rear, and side wall reflections are of less importance. Considering these, and other acoustical concepts, for a balanced sound it is more favorable if the bassoons are framed by the clarinets and horns, not placed at the sides. This helps to reduce the prominence of wall reflections for the instrument.

Because it is very important for the clarinets to be able to radiate freely, it is more favorable to have two tiers for the rows of woodwind instruments than it is to have all the players sitting on one level. This allows the clarinets and oboes, which need unhindered radiation of sound to the front, to radiate freely above the other instruments of the orchestra without absorption of the sound by other musicians. The question of whether the clarinets
should sit on the left or the right of the bassoons in such arrangements is not important to the overall sound of the woodwind group. The position of the clarinets is decided, therefore, mainly by the choice of the position for the horns.

The seating order of the oboes and flutes in the front row is also not significant in the overall balance in most halls. Occasionally it can happen that a very strong piccolo influences the symmetry of the orchestra if it sits on the extreme edge. In this case an exchange of the flute and oboe sections might be advisable.

The woodwinds usually occupy the first risers on the platform directly facing the conductor. Placement is generally in two tiers with the principals placed together in the center. Since this is the arrangement to which the woodwinds are accustomed, it is important for the conductor to consider this aspect when positioning the instruments.

The woodwinds -- after weighing the acoustical possibilities, logistical concerns, and their familiarity with particular formations -- were placed in a three-row, two-tier configuration extending from the main altar area into the second tier of the choir loft. The placement of the horns played a principal role in the determination of this order. There was a careful attempt when placing the horns to allow good contact with both the woodwind and brass sections while avoiding acoustical difficulties of placement too close to either the trombones or the timpani. To accommodate
these needs, the horns were placed on the highest tier level of the choir loft centrally behind the woodwinds. The woodwinds were then arranged in a three-row, two-tier plan directly in front of the horns.

The back row of the woodwinds, positioned on the second tier level of the choir loft, included the clarinets and the bassoons. The clarinets were arranged on the left and the bassoons on the right. This arrangement allowed unhindered radiation of the sound to the front for the clarinet and some absorption of the bassoon sound by the clarinets.

The saxophones were positioned directly in front of the clarinets and bassoons at concert stage height. This position was arrived at principally due to ensemble and space concerns, rather than acoustical principles. The flutes and oboes were placed directly in front of the saxophones on the first row of woodwinds at concert stage level. The flutes were positioned to the left, the oboes to the right. This arrangement allowed for some absorption of the highest frequencies of the piccolo part by the musicians sitting to the player's left, and unhindered propagation of sound to the front for the oboes.

Placement of the Brass Section

We have already discussed the placement of one of the instrument groups in the brass section, the horns, in our discussion of the arrangement of the woodwinds. It is,
however, important to elaborate on the horn's placement. The horns are adversely affected, primarily, by two instruments in the orchestra, the trombones and the timpani. The radiation of sound of the trombone and its effect on the horns has already been discussed earlier in this document. The timpani, when placed too close to the horns, has a tendency to create sudden and violent reverberation traveling up the bell and on to the player's lips. This can have a serious detrimental effect on the reliability of the horns. Therefore, horn players prefer not to be placed extremely close to the timpani or other heavy percussion instruments. Based on our earlier discussion on sound radiation of trombones, placement of the horns either immediately next to, or in front of, the trombones is also not advisable. The arrangement of the horns behind the woodwinds in the final seating plan took into account these problems as much as was physically possible.

The heavy brass are usually placed in either a two-tier block formation or in a single row. A two-tier formation is most effective when the trumpets are positioned behind the trombones. In this type of arrangement, the trumpets do not suffer from a large amount of direct sound coming immediately from behind them. Due to directional characteristics, the trombones are not affected to the same degree by the trumpets when the positions are switched.

For this performance, the heavy brass were situated in a two-tier formation with the trumpets behind
the trombones. The tuba was placed to the extreme left on the same row as the trombones. In addition, in order to avoid the dampening effect of the heavy drapery located on the rear wall in the center of the choir loft, the brass were placed off-center to the left of the conductor. This allowed the trombones to utilize rear wall reflections without extreme absorption of the sound by the drapery material.

In figure 7.2 the final seating arrangement for the orchestra can be noted.

The Choral Seating Arrangement

Space limitations also applied to the arrangement for the chorus. From an acoustical point of view, three points were stressed. First, the arrangement was designed to ensure that there was as little absorption of the voices as possible. This was accomplished by moving the chorus from its traditional placement behind the orchestra, to the sides. This allowed for less absorption of the singer's voices by the orchestral musicians. Second, the issue of masking had to be confronted. By moving the chorus to the sides we were able to reduce the masking between the orchestra and chorus. In addition, the placement of the chorus in a two-tiered platform arrangement helped to reduce the absorption of the sound by other singers.

Arrangement of the chorus in a mixed formation helped to create space between the women's and men's voices.
FIGURE 7.2

ORCHESTRA SEATING ARRANGEMENT
reducing the masking effect in the chorus itself. To aid in the security of the vocal parts, the formation placed the sopranos and basses in a mixed formation on the left side of the stage and the altos and tenors in a similar fashion on the right. Unfortunately, the limitations of space did not allow for the best acoustical space, or distance, between each individual singer. The singers were, however, placed as far apart as physically possible.

Third, the need for the singers to receive direct sound was addressed. By situating the singers to the sides in a semicircular fashion I was able to ensure that each side of the chorus was provided a good proportion of direct sound from the chorus on the opposite side. Figure 7.3 shows the final seating arrangement for the chorus.

Combined Forces Seating Arrangement

In Figure 7.4 we see an illustration of the final seating arrangement for the chorus and orchestra. This arrangement is simply a compilation of the separate formations for orchestra and chorus discussed in the preceding paragraphs.
FIGURE 7.3

CHORAL SEATING ARRANGEMENT

S = Soprano
t = Tenor
B = Bass
A = Alto

AUDIENCE

(ORCHESTRA)
FIGURE 7.4

COMBINED SEATING ARRANGEMENT

STAGE AREA

SYNTH

ORGAN

PIANO

TIMPANI

TUBA

CHOIR LOFT

PERCUSSION
Chapter VIII

Conclusions

In the preceding chapter on the building of a model seating arrangement for Trinity Presbyterian Church, I discussed in some detail the decisions concerning placement based upon the acoustical evidence. It is important, however, to discuss some adaptations and decisions regarding placement that were made due to the personal characteristics of the musicians and the logistics of the space. Making proper decisions in regard to placement based on the personal characteristics of the musicians is one of the major responsibilities of the conductor. Although the primary arrangement was based principally on the acoustical research, human and logistical aspects were included in the final arrangement.

The chorus was arranged in a mixed formation and placed to the sides of the orchestra. The ideal acoustical position would have employed a mixed quartet or scrambled formation with alternation of all voice parts. Due to the difficulty of the demonstration composition and the individual vocal abilities of the singers, a mixed formation placing the basses and sopranos to the conductor's left and the tenors and altos to the conductor's right was employed. The strong singers in the chorus were carefully placed throughout the chorus to help support the weaker singers. The numerical imbalance of parts did not allow for
appropriate spacing and juxtapositioning of all voices. The
tenors, being fewest in number, were positioned with the
altos on the platforms to the right of the stage. It was
impossible to avoid having some altos placed next to each
other. Although not ideal acoustically, the overall strength
of the voices in the tenor section helped to compensate for
this numerical imbalance.

In addition, the height and number of platforms
for the chorus arrangement should be addressed. It is
important to note that the physical space of the concert
location did not preclude a traditional formation locating
the chorus behind the orchestra. The chorus was placed to
the side purely for acoustical reasons. The number and
height level of the chorus platforms, however, was not
ideal. Acoustically it would have been preferable to place
the chorus in a three-tier semicircular formation on the
platforms. Three major problems hindered this placement.
First, despite utilizing all the available platforms at the
university, the number and individual height of the
platforms only allowed for a two-tier arrangement. Second,
the physical space available to the sides of the stage for
placement and the number of singers employed did not allow
for a complete semicircular arrangement. To accommodate the
number of singers in the available space, the final
arrangement placed the singers in a position where they
faced each other across the stage. Although a forty-five
degree angle towards the audience was accomplished when the
chorus was in a standing position, this arrangement did not allow for the ideal amount of direct sound for the audience. This meant that the audience received a greater proportion of side wall reflections rather than direct sound. Third, the average age and physical condition of the chorus played a major role. Since the average age of the chorus was older, particularly the members of the church choir, a position allowing them to sit during portions of the performance was necessary. This also precluded the possibility of using choral risers on the side to achieve a more desirable height for the singers. Quite simply, the physical demands of standing on choral risers for a long period of time would not have been possible for a number of the members of the chorus. The final placement of the chorus reflected all these concerns.

Some slight changes in the position of the orchestra were also necessary. During the first full chorus and orchestra rehearsal it was evident that sight line problems between the conductor and the orchestra existed. Since, once again, the platforming needed to create a more multi-tiered arrangement for the orchestra was not available, some slight adjustments of the orchestral musicians was necessary. The only changes prompted by this problem were the positioning of the harp, flutes and oboes. The harp was simply moved from the conductor's right to the left side of the main stage. This helped reduce the sight line problems between the conductor and the woodwinds. It also had the
added benefit of aiding in the ensemble between the harp and piano. Even with this change logistical problems still remained for the flutes and oboes. The original arrangement with the flutes and oboes on the same row did not allow the physical space necessary for the flutes, particularly the alto flute. The oboes, on the other hand, had difficulty seeing over the double basses on the right of the stage. To accommodate all these needs, the oboes were moved to a separate row in front of the flutes. This meant that the woodwinds were now arranged in a four-row configuration. It is important to note, however, that these changes did not place the instruments at any disadvantage with regard to their acoustical properties. Changing the position of the oboes actually allowed for better forward radiation of the sound since there were fewer musicians placed directly in front of them.

In our concluding remarks we must also address the psychological factor of the position of the chorus and orchestra. Since the process of hearing is both psychological as well as physical, the visual impact of the formation has a positive effect on the aural perception. The visual representation is important when it relates to the form and concept of the composition performed. As Wilhelm Ohmann states in his book *Choral Directing*:

A well planned and meaningful formation is always the prerequisite for music making. Architecture as the 'mother of the fine arts' is also the 'mother of music.' The musical form of the musical
work determines the formation of the musicians. Disorder in the seating arrangement brings about disorder in the music, and a stereotyped formation can result in stereotyped music making. 52

Finally, it can be concluded that an understanding of the acoustical properties of voices and instruments together with an awareness of the architecture and available space of a performance facility may assist the conductor in making decisions concerning the placement of the musicians. Modifications to an ideal acoustical arrangement may be necessitated for reasons of sightlines, availability of risers, numerical balance of voice parts, insecurity of singers and visual impact. Careful positioning will aid the singers and instrumentalists to hear both themselves and others and thus improve their ability to respond as an ensemble.

SELECTED BIBLIOGRAPHY


_____. "Orchestral Sound in Concert Halls." Musical Times 122 (January; February; March 1981):14-17; 92-97; 167-69.


