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THE SYNTHESIS AND MANIPULATION OF LUSID ENSEMBLE TIMBRES AND
SOUND MASSES BY MEANS OF DIGITAL SIGNAL PROCESSING

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Smoot, Richard Jordan
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THE SYNTHESIS AND MANIPULATION OF FUSED ENSEMBLE TIMBRES
AND SOUND MASSES BY MEANS OF DIGITAL SIGNAL PROCESSING

D.M.A. Document
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By
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The Ohio State University
1986

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# TABLE OF CONTENTS

DEDICATION .................................................................................................................. ii
ACKNOWLEDGEMENTS ................................................................................................. ii
VITA .................................................................................................................................. iv
TABLE OF CONTENTS ..................................................................................................... v
LIST OF TABLES ............................................................................................................. vii
LIST OF FIGURES .......................................................................................................... viii

INTRODUCTION ............................................................................................................. 1

CHAPTER

I. Problems of Definition and a Review of Literature Related to Timbre and Timbral Fusion
   A. Fused Ensemble Timbres ..................................................................................... 6
   B. Fused Ensemble Timbres in Other Musical Works .............................................. 8
   C. Timbre .................................................................................................................... 12
   D. Timbral Fusion ..................................................................................................... 18
   E. An Issue Concerning Fused Ensemble Timbres..................................................... 23

II. The Synthesis and Manipulation of Fused Ensemble Timbres and Sound Masses By
    Means of Digital Signal Processing ....................................................................... 25
    A. Vertical Structures in Octandre .......................................................................... 25
    B. Procedures for the Synthesis of Yerevan Sound Masses/FETs by
       Digital Means .................................................................................................. 30

III. A Perceptual Evaluation of Fused Ensemble Timbres ............................................. 35
    A. Problem .............................................................................................................. 36
    B. Procedure .......................................................................................................... 37
    C. Results and Discussion ..................................................................................... 39

IV. Fused Ensemble Timbres: An Ongoing Issue ......................................................... 44
    A. A Speculative Discussion of FETs and Computer Music .................................... 45
APPENDICES

A. Representative Sound Masses in Yarema's Octandra........................................51
B. Description of Instrument Tunes in Storage......................................................55
C. Spectral Analyses of Instrument Tones.............................................................60
D. Description of Synthesized Sound Masses with Sample Spectral Analyses........72
E. Perception Test Results -- Tables and Diagrams..............................................100
F. Spectral Analyses of Eight Test Stimuli.........................................................106

LIST OF REFERENCES..............................................................................................121
<table>
<thead>
<tr>
<th>TABLE</th>
<th>PAGE</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Perception Test Raw Data</td>
<td>100-101</td>
</tr>
<tr>
<td>2. Individual Subject Means and Item Means</td>
<td>102-104</td>
</tr>
<tr>
<td>3. Rounded Individual Subject Means</td>
<td>105</td>
</tr>
</tbody>
</table>
## List of Figures

<table>
<thead>
<tr>
<th>Figures</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Excerpt from Thomas Wells' Piccolo Concerto da Camera (1984)</td>
<td>9</td>
</tr>
<tr>
<td>2. Excerpt from Elliott Schwartz's Celebration/Reflections (1985)</td>
<td>10</td>
</tr>
<tr>
<td>3. Excerpt from Joseph Schwantner's Aftertones Of Infinity (1979)</td>
<td>11</td>
</tr>
<tr>
<td>4. Frequency Distribution of Subject Responses</td>
<td>39</td>
</tr>
<tr>
<td>5. Frequency Distribution of Subject Means</td>
<td>41</td>
</tr>
<tr>
<td>4. Example of FET connection</td>
<td>43</td>
</tr>
<tr>
<td>5. Representative Sound Masses in Mvt 1 of Octandre</td>
<td>47</td>
</tr>
<tr>
<td>6. Representative Sound Masses in Mvt. 2 of Octandre</td>
<td>48-49</td>
</tr>
<tr>
<td>7. Representative Sound Masses in Mvt. 3 of Octandre</td>
<td>50</td>
</tr>
<tr>
<td>8. Short trumpet tone B4</td>
<td>56</td>
</tr>
<tr>
<td>9A. Trumpet tone G#5 -- Attack portion</td>
<td>57</td>
</tr>
<tr>
<td>9B. Trumpet tone G#5 -- Sustained portion</td>
<td>57</td>
</tr>
<tr>
<td>9C. Trumpet tone G#5 -- Sustained portion</td>
<td>58</td>
</tr>
<tr>
<td>10A. Horn A4 -- Attack portion</td>
<td>59</td>
</tr>
<tr>
<td>10B. Horn A4 -- Sustained portion</td>
<td>59</td>
</tr>
<tr>
<td>11A Trombone tone E2 -- Attack portion</td>
<td>60</td>
</tr>
<tr>
<td>11B Trombone tone E2 -- Sustained portion</td>
<td>60</td>
</tr>
<tr>
<td>12A. Trombone tone D3 -- Attack portion</td>
<td>61</td>
</tr>
<tr>
<td>12B. Trombone tone D3 -- Sustained portion</td>
<td>61</td>
</tr>
<tr>
<td>12C. Trombone tone D3 -- Decay portion</td>
<td>62</td>
</tr>
</tbody>
</table>
13. Trombone tone E4 -- Attack and Sustained portions

14A. Trombone tone Bb4 -- Attack portion

14B. Trombone tone Bb4 -- Sustained portion

14C. Trombone tone Bb4 -- Sustained portion

15A. Clarinet tone F4 -- Attack and Sustained portions

15B. Clarinet tone F4 -- Decay portion

16A. Bell tone -- Attack portion

16B. Bell tone -- Sustained portion

17A. Sound Mass #1 -- Attack portion

17B. Sound Mass #1 -- Sustained portion

17C. Sound Mass #1 -- Sustained portion

18A. Sound Mass #2 -- Attack portion

18B. Sound Mass #2 -- Sustained portion

18C. Sound Mass #2 -- Sustained portion

19A. Sound Mass #3 -- Attack portion

19B. Sound Mass #3 -- Sustained portion

19C. Sound Mass #3 -- Sustained portion

20A. Sound Mass #4 -- Attack portion

20B. Sound Mass #4 -- Sustained portion

20C. Sound Mass #4 -- Sustained portion

21A. Sound Mass #5 -- Attack portion

21B. Sound Mass #5 -- Sustained portion

21C. Sound Mass #5 -- Sustained portion

22A. Sound Mass #6 -- Attack portion
22B Sound Mass #6 -- Sustained portion

22C Sound Mass #6 -- Sustained portion

23A Sound Mass #7 -- Attack portion

23B Sound Mass #7 -- Sustained portion

23C Sound Mass #7 -- Sustained portion

24A Sound Mass #8 -- Attack portion

24B Sound Mass #8 -- Sustained portion

24C Sound Mass #8 -- Sustained portion

27A YAFFF -- Attack portion

27B YAFFF -- Sustained portion

27C YAFFF -- Sustained portion

28A YAFFP -- Attack portion

28B YAFFP -- Sustained portion

29A YAPFP -- Attack portion

29B YAPFP -- Sustained portion

29C YAPFP -- Sustained portion

30A YAPPP -- Attack portion

30B YAPPP -- Sustained portion

30C YAPPP -- Sustained portion

31A YAPFF -- Attack portion

31B YAPFF -- Sustained portion

31C YAPFF -- Sustained portion

32A YAPFP -- Attack portion
32B. YAPFP -- Sustained portion ........................................... 114
32C. YAPFP -- Sustained portion ........................................... 115
33A. YAPPF -- Attack portion .................................................. 116
33B. YAPPF -- Sustained portion ........................................... 116
33C. YAPPF -- Sustained portion ........................................... 117
34A. YAPPP -- Attack portion .................................................. 118
34B. YAPPP -- Sustained portion ........................................... 118
34C. YAPPP -- Sustained portion ........................................... 119
INTRODUCTION

The use of timbre as a primary compositional determinant characterizes the output of many twentieth century composers. Today it is common to encounter works wherein the composer emphasizes timbre to such an extent that it becomes an important focus of compositional interest for the listener. The traditional use of timbre for contrast and as melodic carrier is still quite evident in much recent music, but new approaches to the treatment of timbre have been and are currently being developed, especially with the advent of digital signal processing and the integration of live performance techniques with electronic music. Today, the composer wishing to work with timbre as a primary compositional determinant is challenged by the complexity of the subject itself and the dearth of coherent compositional approaches to the subject.

The current study was inspired by Robert Erickson's discussion of fused ensemble timbres (FETs) and sound masses in his book, Sound Structure in Music (1975). In this work, Erickson describes the use of these musical structures by Edgard Varèse and others. Varèse's treatment of timbre may be seen as one of the first coherent approaches to the task of composing with the functioning of timbre as a primary compositional determinant. His work reflects a powerful intuitive understanding of the workings of timbre and precedes the recent, extensive research into this subject area. The present study reports the author's own investigation of the subject of musical timbre and betrays a strong bias for an approach that is intended for composers interested in developing techniques involving the creation of sound masses and FETs using digitally converted instrumental
tones. Yarès's treatment of timbre (and Erickson's concomitant discussion) will be the point of departure in this endeavor and Erickson's main assertions about fused ensemble timbres will be dealt with here. Before proceeding further, a few terms that will be used must be clarified. The main discussion of fused ensemble timbres will be presented in Chapter 1 (p. 6).

The term 'sound mass' has been used by Edgard Yarès to describe sonic structures in his music. He has stated:

When new instruments will allow me to write music as I conceive it, taking the place of the linear counterpoint, the movement of sound masses, of shifting planes, will be clearly perceived. When these sound masses collide the phenomena of penetration of repulsion will seem to occur (Yarès, 1936).

In the music of Yarès, a sound mass can be anything from a single sound produced by one instrument to a sound consisting of tones produced by more than one instrument (Strawn, 1976). The key factor here is that the sound mass is a congealed structure, but not necessarily one within which only one sound can be perceived. In fact, a number of constituent sounds may be evident in some sound masses. In this discussion the term "sound mass" is used to describe a broad category of sounds. Within this category lies the fused ensemble timbre which has the qualification of being so highly congealed that individual component instruments cannot be discerned. It is important to note that Yarès does not use the term 'fused ensemble timbre', rather, Erickson employs this description in his discussion of Yarès's music (Erickson, 1975). In the subsequent discussion, the description "Yarèsian sound mass" is also used. This is qualified here by the author as a structure that bears a strong resemblance to the kind of sound mass that Yarès uses, in
terms of interval content, instrumentation, dynamics and synchronicity of respective instruments. With respect to synchronicity, however, it is important to note that Varèse is constantly processing sound masses, in that he dynamically builds and takes apart these structures. There are many examples of this process throughout his work, but the reader is referred to Movement 1, mm. 9 - 12 of Octandre for one.

Other writers have referred to 'sound masses' (Schaeffer, 1968, Slewson, 1985). Slewson, in his discussion of Pierre Schaeffer's Traité de objets musicaux (1968), briefly describes a rather involved system for classifying sound masses that may be of interest to the reader, but will not be considered here.

The term "timbral fusion" refers to the combination of distinctly different timbres such that a single sound is perceived. This may be evident in the context of a fused ensemble timbre or sound mass. In the case of the former, all component tones would blend as one. In regard to the sound mass, some of the component tones would blend and other might be discernible. The author does not know where this term originated, but it is important to note that it is relevant to the present discussion and consequently, will be discussed in the appropriate context in Chapter 1, Section C, p. 12.

Important aspects of this study include a review of recent research and theoretical contributions pertaining to timbre and timbral fusion that appear to have compositional implications, the examination of Varèse's Octandre, a work in which FETs and sound masses appear to be in evidence, and the practical implementation of procedures for the digital generation of similar structures. In addition to documentation of the FET and sound mass synthesis process, and analysis of the resultant sounds, a perceptual pilot study was designed and carried out in order to evaluate the strength of the FET percept.
This study is not a complete re-examination of the subject of musical timbre. Gray (1975) and Erickson (1975) have clarified the major issues in regard to this subject that will concern us here. Stephen McAdams has dealt with many aspects of the subject of timbral fusion (McAdams, 1964) and this study will not repeat his efforts. It is suggested that the reader consult Grey and McAdams for historical reviews of the subjects of timbre and timbral fusion. Instead, the focus of this work is upon the creation of Varèsean sound masses that may also be perceived as fused ensemble timbres, and relatedly, the contributions of Erickson, Grey, McAdams, and others will be considered. The major result of this effort has been a number of sounds that have been and will be useful to the author in his own compositional work, as well as the delineation of a generative process involving sampled instrumental sounds, at a time when such an approach is of great interest to composers working in computer music. This generative process will be described in detail. Presently, composers and researchers are actively seeking a descriptive system of timbre-based relationships; and the procedures described here may prove to be of interest in that the Varèsean sound masses, created as part of this project, are intended to serve as continuous bridges between traditional acoustic instruments and computer-generated sounds. With respect to this latter concern, this document describes the initial phase of an ongoing compositional research project that engenders the codification of procedures for generating interesting sonic structures and compositional applications of these structures in a formal capacity.

The perceptual evaluation of one of the sound masses, generated as part of this research, is not intended for experimental psychologists, but rather, for composers who recognize that musical art can benefit by the occasional foray into the empirical realm.
The author's intention was to develop an orientation for research involving the fusion of acoustic instrumental tones and to suggest an investigative approach to this complex subject. Overall, this perceptual evaluation is a subsidiary aspect of the current research, the overriding concern being the generation of useful sonic materials. Nonetheless, such an investigation is important in that it forces consideration of fusion in musical contexts. In fact, the author is very interested in the pursuit of a compositional aesthetic wherein the fused sound is treated as the goal of generative musical activity and, as a result, the clearest description of the fusion process is necessary if control is to be exercised in this endeavor. This latter interest will be treated in the last chapter of this study. It should be noted that the process of experimentation with sound masses intended for fusion has been somewhat arbitrary and conjectural in nature; but, with respect to the study of fusion using digitally recorded instrumental tones, we have little information to rely upon and must proceed somewhat arbitrarily.
CHAPTER 1: Problems of Definition and a Review of Literature Related to
Timbre and Timbral Fusion.

A. Fused Ensemble Timbres.

Robert Erickson has described certain musical structures found in the music of
Edgard Varése as "fused ensemble timbres" (Erickson, 1975, pp. 46–47). According to
Erickson, such a structure is perceived as "a single fused timbral entity" (Erickson,
1975, p. 46) as opposed to one in which discrete tones from a vertical sonority can be
detected. He establishes the following criteria as the basis for defining fused ensemble
timbres (FETs). They are, those sounds that show:

(a) a (precarious) balance of forces, where
(b) individual instrumental sounds lose their
identifiability, and where
(c) an unexpected, or striking or otherwise
memorable fused sound is in the perceptual
foreground.” (Erickson, pp 46-47)

Erickson presents examples from works by Schoenberg, Webern, Stravinsky, Debussy
and Varése containing sounds that fit his criteria for FETs. He considers Varése to be
outstanding in his treatment of timbre and as a creator of fused sounds.

Erickson has stated that “there are many degrees of separation and fusion” and
a composer interested in creating FETs must deal with complex possibilities in taking a
systematic approach to this endeavor. The construction of FETs requires attention to
duration, harmonic content, amplitude balance of component tones, dynamic fluctuations,
synchronicity of onset and decay and, quite possibly, performance hall characteristics,
according to Erickson (Erickson, p. 46). Additionally, there appears to be a perceptual tendency on the part of listeners to resolve constituent tones in a massed sound as recognizable instrumental sounds, much in the same manner that overlapped shapes can still be discerned as recognizable objects in visual perception (Erickson, 1975, pp. 26-28). Whatever the case, the music of Varèse may evince procedures that cause the listener to engage in something other than the ordinary music perceptual processes, at least with respect to the parsing of individual instrumental sounds in an ensemble context.

The speculative argument presented by Erickson serves to unveil an issue of ongoing compositional interest involving the formation of sounds that he describes as timbral objects; but the complex nature of this subject requires that the composer turn to the experimental literature if reliable compositional methods are to be developed for synthesizing sounds that qualify as FETs. The multifarious possibilities that arise when a composer begins grouping sounds vertically, as has been suggested by Erickson, may well lie upon a continuum between fusion and non-fusion; and at different points upon this continuum a varying number of discernible sound parts may be evident in the sound. In some cases FETs may be heard and in others, another variety of sound mass may be evident. Examination of representative works by Varèse may lead to the conclusion that he composed with the idea of a continuum in mind creating movement that is characterized not only by distinct changes of timbre, but also by movement to and from states of fusion and non-fusion. Nevertheless, anyone who attempts to derive a clear sense of process from his work will probably be put off by the lack of systematic analytical approaches to his music — which is not to say that such approaches cannot be developed.

Fusion in the music of Varèse will be considered further, but discussion of other
composers' efforts and a brief preliminary review of literature--related to the subjects of timbre and timbral fusion--is in order first.

B. Fused Ensemble Timbres in Other Musical Works.

FETs can be found in the work of composers besides Varèse and those mentioned earlier in Erickson's discussion (e.g. Schoenberg, Webern, etc.). The reader is referred to the examples of their work in Erickson's book. It is of interest to note that a number of contemporary composers have made use of this kind of sound although not necessarily in the context of an exclusively timbre-oriented aesthetic. A few musical examples will be presented from the work of three composers that, in the author's judgement, qualify as fused ensemble timbres. These composers are Joseph Schwantner, Elliott Schwartz and Thomas Wells, and each artist has developed a style in which an acute sensitivity to compositional possibilities involving timbre is manifest. All of the examples from their work will be presented as piano reductions with the instrumentation indicated. The reader should consult the original scores for more information concerning musical context.

The first example is from Thomas Wells' Piccolo Concerto da Camera (1984) in which a sound appears four measures after rehearsal no. 33 with the following characteristics [See Figure 1 below--All instruments are given at the sounding pitch]
This composer relies upon the spectral reinforcement of percussive sounds to create this FET [Note tam-tam which is notated as A2 and use of piano cluster]. Also, the cello B-flat and violin B-natural combination probably contributes to a situation where the listener has trouble discerning constituent instruments. The interested reader will undoubtedly be able to locate similar structures in the music of this composer.

Elliott Schwartz's *Celebrations/Reflections* (1985) contains a number of examples of sounds that appear to be FETs. One example can be found in m.71 consisting of brass, woodwind, strings and percussion. Here the composer relies upon short duration, high volume and sharp attack to create a fused sound [See Figure 2 below]
Schwartz's work is characterized by many interesting sound masses and FETs as well as an overall unique approach to the compositional treatment of timbre warranting further investigation.

Joseph Schwantner's focus upon timbre is evident in many of his works. His Pulitzer Prize winning composition, *Aftertones Of Infinity* (1979), is an example of a work that is governed by a unique aesthetic characterized by an interesting harmonic language and remarkable timbral activity. Figure 3 contains a reduction of a sound heard at the closing of the work (See figure 3 below).
Figure 3: Excerpt from Joseph Schwantner's *Aftertones of Infinity* (1979).

This example is one of many in this composition that seem to be fused. The pitch structure, dynamic level and instrumentation seem to augment fusion in this case.

Three distinct approaches to the creation of FETs have been referred to herein. There are others. One other notable composer is Gérard Grisey, whose *Modulations* (1978) is virtually a study in the creation of fused ensemble timbres. The important point is that numerous approaches can be taken and most likely, the composer with a good intuitive understanding of instrumental possibilities will have the greatest success creating fused sounds.
C. Timbre.

John Grey's exhaustive dissertation, *An Exploration of Musical Timbre* (1975), will serve the interested reader as the best reference for a review of the experimental literature related to timbre. Also, Erickson's book provides the composer with a wealth of information concerning compositionally relevant experimental contributions to the study of timbre. The present research, for which there is no known precedent, will best be served by the examination of select, related research topics and a working definition of the term timbre.

Both Erickson and Grey have noted the definition of timbre provided by the American Standards Association. It bears repeating here.

Timbre is that attribute of auditory sensation in terms of which a listener can judge that two sounds similarly presented and having the same loudness and pitch are dissimilar...Timbre depends primarily upon the spectrum of the stimulus, but it also depends upon the waveform, the sound pressure, the frequency location of the spectrum, and the temporal characteristics of the stimulus (American Standards Association, 1960).

In response to this definition, Grey has said:

It is easy to see why there exists no commonly accepted model for timbre, but rather there are large discrepancies in the specifications found in the literature for timbre. In essence, then, timbre may comprise any subset of acoustical phenomena other than pitch and loudness (and, we might add, [Grey's comment] duration and spatial location) (Grey, 1975).

Recent research indicates that the term "timbre" describes an acoustical phenomenon that is multi-dimensional in nature and characterized by activity on a number of levels. Hermann von Helmholtz described timbre as a product of the harmonic constitution of a
tone, attributing sound color to the relative amplitudes of partials and the temporal envelope (Helmholtz, 1877, pp. 65-69). Indeed, subsequent studies clearly indicate that basic steady state differences in timbre are strongly affected by these characteristics. Even so, the subject is more complex than this. We know, for example, that a major cue for the identification of musical instruments comes from the attack segment of a tone (Seldanha and Corso, 1964). This idea is reinforced by other research which indicates that the spectral evolution of the constituent harmonic partials within the attack portion of a sound is a determining factor, (Strong and Clark, 1967a, 1967b, Risset, 1966). Dodge and Jerse’s discussion of Risset’s analysis of trumpet tones illuminates the point concerning spectral evolution quite well.

The spectrum of a trumpet tone is nearly harmonic; the higher harmonics become richer as the overall intensity increases; there is a fluctuation in the frequency of the tone that is fast, small in deviation, and quasi-random successively higher harmonics have slower rises to maximum amplitude during the attack; and there is a formant peak around 1500 Hz (Dodge and Jerse, 1985, p. 57).

Risset also made the important observation, based on the same analysis, that each partial of the trumpet tone has a different amplitude envelope. This is in contrast to the earlier conception in which the envelopes are viewed as one (Dodge and Jerse, 1985, p. 57). Sample spectral analyses of instrumental tones can be found in Appendix B that may help to illustrate the point concerning spectral evolution. The first example on p. 60 is a representation of a short trumpet tone at the pitch of B4. In this case the evolution of higher harmonics can be seen. As well, the longer trumpet tone (G#5) given on pp. 61-62 illustrates the point concerning spectral evolution even better. The light traces
in the upper frequency regions are representations of spectral energy and it is interesting to note the prominent formant that gains amplitude energy as the tone evolves [See the second bend of energy from the left]. An examination of the spectral analyses given for horn (p. 63), trombone (pp. 64-69), clarinet (70) and bell (p. 71), support the idea that spectral evolution is a prominent characteristic of all acoustical instruments and most likely, an important determining factor of their respective timbral qualities.

Equally important to our understanding of timbre is the aforementioned concept of formants. Grey notes:

A supplement to the classical theory of Helmholtz was the notion of formant regions in the harmonic series. A formant is a particular frequency range in which harmonics are much higher in amplitude than the harmonics in neighboring ranges (Grey, p. 4).

Grey goes on to describe the derivation of the spectral envelope of a complex sound wherein the formant(s) appear as peaks in the spectral curve. He points out that "...In view of more recent studies on the role of critical bandwidths in hearing...the formant model presents a more complete framework for understanding the perception of a spectral envelope" (Grey, p. 4).

Critical bandwidths have been defined by Grey as follows:

Critical bandwidths have been empirically defined as frequency regions in which the ear seems to integrate acoustical stimulation. These bandwidths are continuously spread along the frequency axis, and are roughly 1/3 octave in width. The exact size of a critical bandwidth varies with the absolute frequency region in which the particular phenomenon is being measured (Grey, p. 4).

The concept of critical bandwidths is important to our understanding of formants and may
provide a partial explanation for our perception of timbre.

Timbre is not invariant with respect to pitch and loudness (Clark and Milner, 1964). Musicians will testify that the general quality of an instrument’s sound often changes as we move throughout its range; for example, compare the clarinet’s lower and upper range. To describe what is heard they may use terms such as “brightness” or “roughness” considering two that Gray mentions (Gray, p. 7). But a spectral analysis of such a timbral change will reveal a phenomenon of greater complexity than such terms might suggest. Spectral analyses have been given for the following trombone tones from throughout the range at the forte dynamic level: E2 (p. 64), D3 (p. 65), E4 (p. 67), Bb4 (p. 68). These analyses illustrate, in a very basic way, the extreme differences that occur spectrally as we move across the instrument’s range as well as the earlier point concerning spectral evolution of harmonic content. A similar situation may exist with respect to loudness changes also. The trombone manifests significant change in the spectrum as the player moves, for example, from piano to double forte. Consequently, any compositional technique that primarily involves timbre, must account for the fact that spectral change may be prominent as dynamic and pitch conditions change. It is not hard to imagine the difficult situation confronted by the composer who attempts to work with timbre and systematically deal with this condition.

John Gray concludes that instruments can be classified across the lines delineating traditional, instrumental families, based on similarities shared timbrally with other instruments when tones from different families but the same part of the range are compared (Gray, 1975). Using multi-dimensional scaling techniques to evaluate comparisons of re-synthesized instrumental tones, he found that some instrumental tones
are closer spectrally to the same part of other instruments' ranges than they are to tones taken from a different part of their own range. It is possible that the same condition exists with respect to loudness: a given instrumental tone may be closer spectrally to a tone from a different instrument but from the same part of the dynamic range, than to another tone from the same instrument but from a different part of the dynamic range. This represents an area worthy of future investigation; maybe a methodology can be developed for systematizing this information.

It is apparent from the literature dealing with timbre that individual tones, produced by acoustical instruments, are in no way stable entities. In fact, studies have revealed that the degree of activity within an instrumental tone of even short duration is remarkable, involving staggered entrances of partials and variable intensity changes of formants and individual harmonics, attack transients and noise factors [See spectral analysis of short trumpet tone, p. 60] Comparisons of different instruments and instrumental families will reveal that the attack, steady state and decay characteristics can vary significantly from one instrument to another, factors which, along with formant changes, intensity changes and other dynamic variables, lend instruments their particular tone colors and has probably contributed to the delineation of instrumental families. A number of important studies have been made of instruments (e.g. Risset's study of trumpet tones, 1966) and instrumental families; the interested reader should consult them for detailed information.

The problems inherent in the definition of timbre can be ascertained from the literature. The lack of systematically, organized information about this subject, especially relating to particular instrumental characteristics across their respective
ranges, makes it very difficult for the composer trying to formulate compositional techniques and approaches where timbre is a primary compositional determinant. In order for composers to be able to work reliably with timbre, it is essential that information be available pertaining to spectral characteristics of instrumental tones from entire frequency ranges. Additionally, complete information is necessary relating to spectral change under varying dynamic conditions throughout entire ranges. Obviously, this is a tremendous quantity of information, but the means for acquiring, organizing and storing these data exist and should be employed.

It is clear that the subject of musical timbre is complex. Studies confirm that realism in instrumental tones is, in large part, the result of a tremendous amount of activity on the micro-level. Some methods of data reduction have been successful and have allowed researchers to develop methods for synthesizing naturalistic tones using digital synthesis (e.g. Grey's line segment approximations, 1975). These efforts have probably been fruitful because of the researcher's attention to the intricate properties of timbre when resynthesizing tones. This kind of detailed effort is essential if composers and researchers are to be successful with the creation of new sounds based upon the complex characteristics of natural sounds. Also, efforts to integrate traditional instruments with computer-generated sounds requires a clear understanding of the intricacies of timbre.
D. Timbral Fusion.

An understanding of recent research relating to timbral fusion is strongly pertinent to any discussion of fused ensemble timbres. Stephen McAdams has been involved with the study of simultaneous, multiple sound sources as single, fused percepts and his work has contributed valuable information to our understanding of the perceptual and physical mechanisms operative in auditory source formation, considering both simultaneously and sequentially organized sound events. His dissertation, Spectral Fusion, Spectral Parsing and the Formation of Auditory Images (1984) is the best source on the subject of timbral fusion, and important aspects of this work and others will be presented here.

McAdams has adopted the descriptive term "auditory source image" to serve as a metaphor useful in describing the results of auditory organizational processes to composers, musicians and psychologists (McAdams, 1984, p. 290). He states:

To summarize briefly, the auditory image is a psychological representation of a sound entity exhibiting a coherence in its acoustical behaviour. The notion of coherence is necessary, if rather general...Since any natural and interesting sound event has a complex spectrum evolving through time, often involving noisy as well as periodic and quasi-periodic portions, it is important to consider the conditions under which these acoustically disparate portions cohere as a single entity...I have introduced what I consider to be the most powerful asset of the metaphor. It allows for a hierarchical or multi-levelled approach to auditory organization. We can consider a single trumpet as an image and speak of its properties as a tone, for example, pitch, brightness, loudness. We can consider a whole sequence of trumpet tones as an image and speak of its properties as a melody. All of this is to say that the metaphor allows the development and application of a broad set of criteria for musical coherence to be applied to music as a grouping and parsing of sound events (McAdams, 1984, p. 291).

In order to enhance our earlier definition, we can note that fusion is a perceptual
phenomenon wherein multiple sound elements are perceived as single, which is to say that they cohere as a single entity. Concomitantly, the term "parsing" refers to the capacity and, perhaps, even the tendency for the auditory system to differentiate sound elements and resolve them to constituent, and, often, familiar parts. McAdams has investigated the dominant mechanisms involved in this perception and conducted a number of experiments, often in collaboration with other researchers, in order to test his hypotheses. The results of these efforts are intriguing.

McAdams presents three criteria that contribute to the formation of single, auditory images: "(1) coherence of amplitude modulation across a sub-group of spectral components belonging to the same source; (2) coherence of frequency modulation across a spectral sub-group; (3) stable resonance structure forming the amplitudes of a spectral sub-group..." (McAdams, 1984, p. 298). Elsewhere, he has stated the conditions as follows: "(1) the harmonicity of the frequency content of a tone, (2) the coordinated modulation of the spectral components, and (3) the relative familiarity of the spectral envelope" (McAdams, 1982, p. 281). It is possible that the absence of one or more of these conditions facilitates the parsing process.

Considering the works cited above and McAdams' dissertation, it would appear that fusion can be brought about if certain conditions are in evidence. The key word in this endeavor appears to be "coherence." First of all, McAdams' studies indicate that the coherent amplitude and frequency modulation of the spectral components in a sound contributes to spectral fusion. A number of different modulation conditions were tested. In reference to amplitude modulation in natural sounds, he sees the overall amplitude envelope, as well as fluctuations in intensity and tremolo as coherent kinds of
amplitude behavior. Also, he points to the "onset synchrony of spectral components and amplitude fluctuations across these components during a sustained tone" (McAdams, 1984, p. 298) as important factors affecting fusion. It has been pointed out that the asynchronies evident in the onset of the partials of most natural sounds are less than 20 msec and the perception of a sound as being fused begins to fall apart when they exceed 20-30 msec (McAdams, 1984, p. 298). Additionally, his comparison of synchronous versus asynchronous amplitude modulation of spectral components indicates that fusion is promoted by coherent, synchronous modulation patterns and that incoherent ones [See definition below] contribute to the perception of multiple sound images (McAdams, 1984, pp. 298-300).

McAdams employed two basic types of frequency modulation to test for the coherence of this factor when applied to the spectral components of a sound. He describes them as vibrato (periodic frequency modulation) and jitter (aperiodic frequency modulation). He states:

..."coherent frequency modulation" is modulation maintaining the frequency ratios of the partials. With computer synthesis, this can be applied to sustained inharmonic tones as well as to harmonic tones...It can be seen that if a frequency modulation (vibrato or jitter) is imposed on the partials of a harmonic tone complex such that the ratios are not maintained, the complex "defuses" (McAdams, 1984, pp. 300-301).

It should be noted that McAdam's distinction between "vibrato" and "jitter" may not be clear to most musicians. Both of the described conditions are normally referred to as "vibrato" by musicians. McAdams arbitrarily restricts the term "vibrato" to periodic frequency modulation and adds a new category for aperiodic frequency modulation, which
is actually another form of vibrato. This potentially confusing distinction must be considered when the reader encounters these terms.

McAdams also conducted an experiment where fifteen partials of a sixteen component tone were modulated coherently and one was modulated incoherently, with each partial being tested as the incoherently modulated one at some point. He reports that "Several perceptual effects resulted depending on which harmonic was modulated and on what the overall modulation width was. Either certain partials stand out as separately audible (with lower partials modulated) or a kind of 'choral effect' results where an illusion of multiple sources is heard (with higher partials modulated)." (McAdams, 1984, pp. 301).

McAdams describes a coupling of frequency and amplitude modulation that "...serves to define the spectral contour of a complex tone and in certain cases may actually reduce the ambiguity of the resonant identity of the sound source." (McAdams, 1984, p. 304). He notes "...that as the frequencies modulate, their amplitudes change such that each partial traces a small portion of the spectral envelope, that is, the frequency-amplitude curve describing the overall spectral form." (McAdams, 1984, pp. 304). Essentially, all of the spectral components, including formants, are 'outlined' by this modulatory activity. In the case of sounds where the formant structure serves as a strong perceptual cue, the coherent modulation of the formants appears to promote a strong sense of fusion, according to McAdams.

One last issue should be considered as an essential part of this overview of the current research relating to timbral fusion. This is a question concerning the effect of harmonicity on the formation of single auditory images. McAdams notes that
"psychoacoustic and physiological research...indicates that the auditory system is biased toward the processing of harmonic, as opposed to inharmonic sounds" (McAdams, Dias, 1984, p. 41). Apparently, the harmonicity of the spectral components of a given sound is a strong determinant of fusion. McAdams says:

Harmonic tones fuse more readily than inharmonic tones under similar conditions and the degree to which inharmonic tones do fuse is partially dependent upon their spectral content. In general, as a sound is transformed to be less like the purely harmonic case, there is a decrease in the perceived fusion (McAdams, 1984, p. 42).

He notes, elsewhere, that the presence of acoustic signals, each with a separate harmonic series fosters the perception of multiple tones and, perhaps, multiple sound sources (McAdams, 1984, p. 303). In respect to the choral effect, created, for example, when several violins play together, he makes the following observation:

[Each instrument] has its own independent jitter modulating all of its harmonics. When we add all of the sources together we get these random movements of frequencies beating against one another creating quite a complex situation acoustically. In addition, as one moves into the higher harmonics, the patterns of stimulation on the basilar membrane move closer and closer together until they are heavily overlapping. In these regions, the incoherent movement of adjacent harmonics is creating a complex stimulation for any given auditory nerve...[as a result] there is a limit to how many sources you can pick out... (McAdams, 1984, pp. 301-303).

The choral effect (Roederer, 1979, p. 145) has been described as "the sensation of several almost identical sounds in near fusion" (Butler in Wells, 1981, p. 27), the product of several instruments slightly out of sync, and it may also entail some action within the auditory system involving stimulation of the basilar membrane within a critical bandwidth. A single image may be the result of a kind of auditory system overload.
where the sum of complex activity is taken by the auditory system as a sound mass, and perhaps, given the right conditions, a fused sound. In fact, if Erickson is right, the possibility exists that certain inharmonic combinations of sounds may contribute to the formation of fused percepts, a possibility that will be considered next. As analysis of his music reveals, Varèse displays a strong preference for inharmonic sounds and sounds that, in general, are so complex that the listener has difficulty resolving the constituent parts. It might be assumed, based upon Erickson’s discussion of FETs, that he believes that certain complex sounds overload the auditory system, with the result in some cases being fused ensemble timbres.

E. An Issue Concerning Fused Ensemble Timbres.

Varèse’s music and Erickson’s book predate the major work that has been done with timbral fusion in the last several years. But as early as 1923, Varèse was developing his approach to composition with timbre in works like Hypermusic (1923) and Octandre (1924). Erickson discusses his ideas concerning FETs in relation to these works and others, but without the benefit of empirical evidence to support his assertions.

McAdam’s work suggests that the complex, inharmonic sounds created by Varèse may not qualify as fused, in that they do not clearly meet his criteria pertaining to harmonicity. The present study is an investigation of FETs in light of McAdam’s research and involves a perceptual evaluation of this acoustical structure as it relates to the subject of fusion. Equally important, the author has attempted a kind of computer-based orchestration using digitally converted instrumental tones. Regardless of the FET question, this effort has brought about a number of interesting and compositionally useful sounds that will be
described at appropriate points in the discussion.

The following discussion describes procedures that involved the creation of FETs/Sound Masses based on the analysis of vertical structures in the music of Varèse. Using this analysis, an attempt was made to define pitch models that would serve as prototypes for the synthesis of similar structures. In Chapter 3, the procedure and results of a pilot study, designed for the purpose of perceptually evaluating one of these structures, will be presented. In the interest of achieving a coherent focus in this work, it was decided to limit analysis to one work, Edgard Varèse's Octandre.

A. Vertical Structures in Octandre

Erickson regards Octandre as a work that demonstrates Varèse's compositional approach to timbre and the creation of fused ensemble timbres (Erickson, 1975, pp. 47-48). It is a work scored for flute, oboe, clarinet, bassoon, horn, trumpet, trombone and bass. To date, only a few studies have appeared dealing with Varèse's music analytically, (Babbitt, 1971, pp. 40-48; Strawn, 1979, pp. 138-160, Stempel, 1979, pp. 148-166), but so far there has been no attempt to describe the relationship between pitch content and Varèse's creation of FETs. In Octandre, there are many vertical structures that appear to conform to the definition of an FET discussed earlier, in addition to the ones that Erickson cites in his book. Any of these structures could be investigated for the fusion effect, but in and of itself, that might not provide much information about
Varèse's technique(s) for creating these vertical structures. It should be noted that the terms 'mass' or 'sound mass' will frequently be used to describe vertical structures in Varèse's music, henceforth. Varèse, himself, and various other scholars (Varèse, 1936, p. 25; Strawn, 1979, p. 140) have set the precedent for use of this word and its employment here allows the description of vertical activity without the presumption that a sound is fused, as in the case of an FET, or functioning as a chord in any traditional sense.

Appendix A contains pitch information for the prominent sound masses in Octandre, based upon an analysis of the entire work. Most of these examples conform, more or less, to Erickson's criteria for fused ensemble timbres. There may appear to be some exceptions. The purpose for this analysis was to derive some sense of Varèse's approach to the use of pitch material to create sound masses in Octandre, the hypothesis being that he systematically employed certain intervallic combinations to create his timbral objects. An examination of this work, as well as others, reveals that he was concerned with the formulation of these objects, as part of a musical process where vertical structures are dynamically created and dissolved, often upon a horizontal plane; and Erickson might add that these structures are dynamically fused and defused at various points throughout the work. He has noted that Varèse was "working not only with fused ensemble timbres, but with the whole range between separation and fusion, and movement between these states is fundamental to his art" (Erickson, 1975, p. 52).

An examination of the pitch material of some of the vertical structures, reveals certain relatively common characteristics. Frequently the masses contain pitches that are a minor or major 2nd apart or, either the inversions of these intervals or the compound forms, usually with other intervals present also. Erickson describes one such structure
In his book (Erickson, 1975, p. 47-48). This example involves horn, trombone and trumpet, and consists of a \(0,1,2\) pitch-class content as illustrated in Mvt. I, m. 18 of Appendix A. This mass moves in counterpoint to another one. In his analysis of Integrales, John Strawn has noted that Varèse's music was not based upon any constant grouping of intervals like a scale or tone row, but notes:

...Varèse seems to have applied a few basic rules of thumb: octaves, for example, are usually avoided. On the other hand, "strong dissonances," such as major and minor seconds, augmented fourths, major and minor sevenths and their octaves occur quite frequently, both in the selection of pitches for a single mass and in the distribution of pitches of masses presented simultaneously (Strawn, 1979, p. 153).

It should be noted that in this discussion the terms "consonance" and "dissonance" are used in accordance with their traditional conception based upon tonality. In general, Varèse's masses are dissonant structures, often with consonant intervals "attached" or "embedded", if present at all (See mass consisting of horn, trumpet, trombone and bass in Mvt. I, m. 19; also see mass with clarinet, bass and trombone in Mvt. I, m. 28). The pitch class information tells us that, quite frequently, Varèse employed vertical structures that used a combination of pitches that included \(0,1\) or \(0,1,2\) pitch-class content. These particular combinations can frequently be derived from any given sound mass/FET, not to mention as part of the general horizontal and vertical organization of pitch material. (see the opening Oboe statement in Octandre). Varèse may have used the most dissonant intervals for two reasons, at least: 1) He wished to create structures characterized by a high degree of tension. And the mixture of relatively consonant intervals and strongly dissonant ones, within various masses, may have been part of an approach that viewed the
variation of interval combinations, with respect to the presence or absence of consonant and dissonant elements, as a means for controlling relative tension within the musical work. 2) Yarèse employed strongly dissonant intervals in combination to overload the auditory mechanism and make it extremely difficult to discern the constituent tones in his sound masses, essentially as a means of creating a single percept. Following Erickson, this would amount to a kind of 'inharmonic fusion,' the result of extreme roughness and, concomitantly, maximum stimulation of the basilar membrane.

An examination of Appendix A will suggest the complexity of the problem inherent in any investigation of these masses for fusion effects. A systematic relationship between pitch content and instrumentation does not appear to be in evidence. Generally in Octandre, Yarèse tends to mess his sounds according to instrumental families, with the bass playing a variable role with respect to the instruments with which it is grouped. All instruments are used, at times, to create sound masses. But the variability of instrumentation within sound masses seems to be consistent with an aesthetic that calls for continuous timbral variation, apparently in conjunction with Yarèse's personal sense of musical process. He has described this:

...an idea, the basis of an internal structure, expanded and split into different shapes or groups of sound constantly changing in shape, direction, and speed, attracted and repulsed by various forces. The form of the work is the consequence of this interaction (Schwartz and Childs, 1967, p 203).

Given that Yarèse conceived his music with the infinite variation inherent in nature as his imitative domain, it was not necessarily in his best artistic interests to adopt a system that might prove to be confining, timbrally or otherwise. Yarèse was a 'sound sculptor'...
who appears to have conceived his music with some kind of visual analogy in mind. He apparently did not adopt an a priori system for generating his sounds and allowed himself great freedom in the arrangement of his materials, within a given work and from work to work. This is not to say that he did not work systematically, or that he did not work with known quantities. In fact, as we have noted, one does not have to look too far to perceive some order in his construction of masses with respect to the intervals used. Given that the instrumentation of Octandre is marked by extreme complexity, it was decided instead to focus upon the pitch factor as a basis for sound mass synthesis in this study. There are some cases where the instrumentation was experimented with. But overall, interval content was emphasized in an effort to determine if sounds consisting of certain intervals resulted in Varèsean sonic structures.

The procedures to be described were part of an endeavor involving computer simulation of Varèseian sound masses. Initially, the process involved the recording of entire instrumental ranges from several instruments. In each case, the ranges were recorded under two or three different dynamic conditions, as well, separate recordings were made for some instruments under variable attack conditions. It was not intended that all of this large quantity of information be used as part of the present research effort. In fact, a relatively small part of the recorded information was employed. However, the current research program was designed with one subsidiary objective being the storage of instrumental sounds covering many performance conditions. All of this information will be available to composers and researchers working in The Ohio State University Sound Synthesis Studios in the future, as part of the permanent library of materials. A complete listing of available instrumental sounds is given in Appendix B. This includes sounds that have already been digitally converted and are in computer storage. The remaining sounds are stored on digital tape. Spectral analyses for sample tones, taken from points throughout various instrumental ranges, are also given in Appendix B.

Some of the synthesized sound masses/FETs were based directly upon the intervallic structure of masses found in Octandre while others were derived from them. In such cases, clarifying information is given as part of the sound mass description in Appendix C. Others sound masses were derived using <0,1> or <0,1,2> pitch-class content with other intervals added arbitrarily, basically following a <0,1,...n> or <0,1,2,...n>
conceptual schema. Using these procedures, the author hoped to derive sonic structures that were similar in general character to those used by Yerese as well as to create structures that might be perceived as FETs. Initially, a number of timbrally different instruments were used in variable combinations to create the sound masses. As the research project progressed, the instrumentation factor was constrained and sounds were generated using only trombone tones. This approach was taken in order to determine whether or not varying the interval content promoted fusion, while the instrument color was constant with respect to instrument type. Beyond this, decisions concerning instrumentation and pitch content were arbitrary and based upon the author’s intimations as to what would constitute an interesting and compositionally useful sound, as well as either a fused sound or a sound that can be described as being highly congealed. Future research projects will address the instrumentation dimension in a more systematic manner. A description of the content of each sound mass/FET can be found in Appendix C along with spectral analyses. A tape of these sound masses will also be available.

The use of $<0,1>$ pitch material, among all of the synthesized sound masses/FETs, is constant, but the placement of intervals derived from this ordering varies. In Sound Mass #1, for example, the semitone is the bottom interval, while in Sound Mass #6, the minor 2nd is the middle interval. This kind of variation can be seen throughout the collection of masses/FETs in Appendix C as well as commonly in Yerese’s sound masses (See examples in Appendix A).

In Sound Mass #1, we can see evidence of spectral evolution and what appears to be beating in the lower frequency band. This would be logical considering that the two lower pitches are A and Bb. The most prominent upper band may be a significant trumpet
formant or a formant created as a result of prominent high frequency energy from all three sounds. This band enters late, and slowly gains amplitude energy which subsides a bit after about 1 second. In the author's opinion, this mass sounds most congealed after that same point, suggesting that the equalization of bands of high amplitude energy might affect perceived fusion.

Sound Masses 2 and 3 contain all trombone tones and all clarinet tones, respectively. The pitch content for these two masses is indicated in Appendix D (p. 72). The interval content is the same for both. In the author's opinion, the mass with clarinet sounds does not seem to be well congealed, possibly the result of the sparseness of the clarinet spectrum (See spectral analysis of clarinet tone in Appendix C). The trombone version sounds more highly congealed to the author, a possibility which might be attributed to the greater spectral density of the trombone spectrum. In regard to the relationship between fusion of sounds and spectral density, McAdams has said:

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Sparsely populated spectra with partials that are easily resolved by the auditory system, i.e. the components are all in separate critical bands, are very difficult to fuse into a single object, even more so if one desires to sustain them over any period of time. The moment they are not heard as percussive sounds they are heard as chords. Fusion is more easily achieved with denser sounds... (McAdams and Saarilho, 1985).
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The spectral analyses of these two sounds, provides evidence of the general difference in regard to spectral density. If McAdams and Saarilho are on the right track, masses like Sound Mass 2 may be the product of a synthesis procedure that can result in fused sounds. Despite this, the prominence of a few amplitude peaks present in the spectral analysis of this mass (See far left frequency region below 2.400 kHz.) leads the author to
believe that some kind of selective equalization might be used to augment the fusion process, in that these peaks may be perceptually salient features of the sound mass.

An examination of the spectral analyses of the remaining sound masses reveals a marked similarity to Sound Mass #2. Interestingly enough, the analyses resemble the bell tone analysis on p. 71 of Appendix C with respect to a lack of regularity in the amplitude activity in spite of the aforementioned few prominent amplitude peaks. Of course, the sonic contrast between the bell and any of these masses is notable, and the spectral analyses are only crude depictions of general spectral activity. Nonetheless, an examination of these analyses may help us decide what treatments to perform next on a given sound mass, that may not be characterized unequivocally by fusion (e.g. equalization of frequency components/areas). Various treatments for these sounds will be discussed further in Chapter 4.

A few descriptive comments should be made concerning the application of digital techniques to this process. Instrumental tones, including entire instrumental ranges, were recorded using a SONY PCM-701ES Digital Tape Recorder and then digitized using a PDP 11/45 computer with 16 bit D/A conversion. Instrumental tones chosen for use in a given sound mass were subjected to a program allowing the delineation of envelope characteristics and overall duration. Once the individual tones had been properly segmented, they were mixed using resident digital mixing programs. Controls for synchrony, amplitude and envelope were imposed upon the resulting sound masses. Spectral analyses were made of the final products. Subsequently, sounds were stored on hard disk. All programs used in this research were developed by Gregory Proctor, Thomas Wells and Neal Yocom and all procedures were implemented in The Ohio State University.
Sound Synthesis Studies.
CHAPTER 3: A Perceptual Evaluation of Fused Ensemble Timbres.

One may intuit, upon hearing some of the synthesized sound masses described previously that they either either fuse or are highly congealed. The author has already made use of some of these masses in his music, particularly because of their perceived congealed quality. Yet it may be contended that no definitive statement can be made concerning the fusion of these sounds, with intuition alone as a basis. Because of this, it was decided to implement a pilot study that would serve as a perceptual evaluation of one of the proposed fused ensemble timbres. Part of the goal of this endeavor was to illustrate the fact that procedures need to be developed that will assist composers in the creation of sounds, in this case FETs, that are of a demonstrable quality. Erickson has pointed us in a particular direction in raising the fused ensemble timbre issue, as well as placing it within a compositional framework; and McAdams has provided the beginnings of an empirical perspective on the subject of auditory image formation. At times, though, Erickson makes reference to the fused ensemble timbre as if it is an undeniable sound percept. Indeed, upon hearing Varèse's music, our basic intuition may well lead us to conclude that Erickson is safe in his assertions about FETs. On the other hand, the composer wishing to exercise control in the synthesis of these structures may wish to know specifically how some of the operant variables should be treated. Perceptual evaluations of FETs, wherein certain variables are controlled for, could put us on the track leading to greater freedom in the creation of these sounds. Still, the question may arise as to why a perceptual evaluation should be made at all, and why the composer should
not be left to make his or her own decisions concerning the fusion of a given sound and its musical value. The implementation of a particular test design intended to treat musical subjects is hazarded by the fact that this usually involves the reduction of information and a context that may appear to be unmusical. The final results, once subjected to statistical analysis may not reflect much about our musical experience at all. Given these reservations about an attempt to perceptually evaluate FETs, the author decided to implement an infant study dealing with the amplitude balance of constituent instrument tones in one of these sounds in order to see if useful compositional information could be obtained.

This study actually considers only a relatively small part of the subject of fused ensemble timbres. This is not to ignore the fact that many other aspects of the FET issue can be examined. For example, studies could be made of any of the masses in Appendix D for fusion effects, not to mention multitudinous others from many other musical works and involving varied instrumentation. It is hoped that this particular study will help to further define the path toward a better understanding of compositional possibilities involving timbral objects, as well as aid in focusing upon the proper areas for further investigation. The problems inherent in research dealing with musical timbre are complex. Nevertheless, small and purposeful investigative steps can be taken.

A. Problem.

The purpose of this study was to determine if one of the sound masses, described in Chapter 3, qualified as a fused ensemble timbre; that is, to say, was perceived as a single, auditory source image under conditions involving the variation of amplitude
balance, while timbre and pitch were held constant. The sound mass evaluated consisted of a particular intervallic arrangement based upon the structure of one Varèsean sound mass in Octandre, and described by Erickson as a fused ensemble timbre. The amplitude balance of the component tones was varied while all other sound dimensions were held constant (e.g. pitch, duration). It was anticipated that the results of this study would yield new information concerning the effect of amplitude balance upon the perception of a sound mass as a fused ensemble timbre outside of any musical context.

B. Procedure.

In order to evaluate the effect of varying the amplitude balance of the component tones of a sound mass upon the perception of it as a fused ensemble timbre, eight sound masses were created using the same pitches as Sound Mass #1 in Appendix C, with duration equalized for all tones, pitch and instrumentation unchanging, and the amplitude of each instrumental tone varied. All eight vertical structures consisted of digitized instrumental tones. The pitch structure and instrumentation is indicated below (U.S.A. Standard octave designations):

\[
\begin{align*}
G\#5 & \quad \text{Tpt} \\
Bb4 & \quad \text{Tbn} \\
A4 & \quad \text{Hn}
\end{align*}
\]
One of two possible dynamic settings were assigned to each of the three component tones resulting in the following eight stimulus patterns:

\[ f = \text{forte}, \quad p = \text{piano} \]

1. \( fff \); 2. \( ffp \); 3. \( fpf \); 4. \( fpp \); 5. \( pff \); 6. \( pfp \); 7. \( ppf \); 8. \( ppp \)

Each sound was processed by a computer program [developed by Gregory Proctor and Thomas Wells at The Ohio State University] in order to insure dynamic equivalence and precisely scaled balance among the component tones. The sounds were each three seconds in duration. The test was given to 24 subjects who were Sophomore music majors at The Ohio State University. All subjects were in their fifth quarter of aural training. The subjects were tested twice, the second day with items counterbalanced to mitigate order effects. During each test, the subjects heard the eight sound masses randomly combined with twelve distractors modelled after the eight main stimuli with respect to pitch, but with different timbres. Subjects were asked to estimate the number of "sounds" heard per stimulus item. Responses were tallied and means calculated for each of the eight loudness combinations, including item means and individual subject means.
The results of this pilot test are shown in Appendix E (p. 100). The raw data are given in Table 1 on pp. 100-1 with the four responses for each stimulus combination given per subject; the individual subject and item means are in Table 2 on pp. 102-4; the standard deviation for item means is shown on p. 104; the rounded means for individual subject are in Table 3 on p. 105; the frequency distribution of subject means is presented on p. 41, and the frequency distribution of subject responses appears below (See Figure 4). A one sample T-test for statistical differences in observed and expected means was carried out. The results led to the rejection of the null hypothesis. Statistical significance was determined for this sampled data at the alpha = .01 level. Also, spectral analyses for each stimulus combination are given in Appendix F, p. 106.

Figure 4: Frequency Distribution of Subject Responses. X = Number of responses per choice. Y = Number of possible choices.
It would appear that most of the subjects do not clearly hear the stimulus patterns as fused. The raw data indicates that there was some confusion in this identification task, but the subject means seem to indicate that subjects were able to discern the number of component tones, overall. It seems that under the conditions brought to bear in this study, varying the amplitude of the component tones does not have a strong effect upon fusion for a sound consisting of these particular pitches. This statement can only be made for these conditions and, as was stated earlier, other pitch combinations should be tried. It might be suggested that a rehearsal effect in this study was strong, given that each subject heard very similar sonic structures sixteen times. The confusion in responses seems to contradict this. Responses are spread out to some extent and do not clearly cluster around the number three (See Frequency Distribution of Subject Means on next page in Figure 5). It is possible that the confusion is the result of some effect of either the pitch structure itself, or the amplitude variation. For example, the item Means for the FPF and PFF stimuli were relatively low (See Table 2, Item Means, pp. 103-4), suggesting that for these combinations the task of discerning component tones may have been more difficult. In general, it is interesting to note the variation in responses, with some individuals hearing four, five and six sounds within a given presentation and others hearing one (See Table 1, Raw Data, pp. 100-1).
It may be that the ability to identify individual instruments in a massed sound is not easily defeated by the other conditions set forth in this test (e.g. control of amplitude balance, synchronicity). The number of stimulus presentations may have served to reinforce somewhat the perception of the number of constituent tones. In a musical context, the possible confusion that a listener can experience hearing sounds of this nature may work to the advantage of a composer such as Yarèse. The listener may by default hear such a sound as highly congealed, at least. It might be asserted that an
out-of-context study like this one says little when we consider that these sounds, heard in
relation to other sounds and musical events, can possibly be taken quite differently by the
ear. Future studies of this nature must account in some ways for more musical situations
where proposed FETs are considered as part of a dynamic compositional process, for
example, the one evident throughout much of Varèse’s output in which a sound mass/FET is
the goal of the motion of several independently moving parts (See the end of Mvt II of
Octandre where the instruments converge, for a good example).

A comparison of the spectral analyses for the stimulus combinations may shed
more light on the subject, remembering that such depictions are, at best, crude
heuristic representations of acoustical activity. We can generally see the result of
varying the amplitudes of the eight stimulus combinations. For example, compare YAFFF
(pp. 105) and YAFFP (pp. 111). The bottom band of spectral energy in all of the
analyses reveals apparent beating between the A and Bb. The higher bands of spectral
energy seem to be characterized by relative amplitude stability, a fact which may have
aided the tracking of frequency components present in these bands; the beating present in
the lower region causing some confusion and resulting in a number of people hearing two
sounds when there were three present (See Frequency Distribution of Subject Responses,
p. 39). It should be noted that a pattern of beating appears in the lower frequency region
for all of the test stimuli. This beating may contribute to a chorus effect for the listener.

It is hoped that the study carried out here will be illustrative for other composers
and researchers who wish to pursue the subject of fused ensemble timbres. It must be
considered, however, that this kind of testing may have little compositional value and that
the approach taken in creating the sound masses in Appendix D bears more immediate and
useful results to a composer. This approach is arbitrary and full of trial and error, and relies on the composer's intuition for evaluation purposes. Some final considerations should be made concerning this study. First of all, the sounds presented here were quite "dry." Future investigations might involve the use of controlled reverberation. Also, it would be interesting to experiment with sounds of short duration, perhaps using a test design similar to this one.
CHAPTER 4: FUSED ENSEMBLE TIMBRES -- AN ONGOING ISSUE.

The study described here is embryonic. We have hardly touched the surface of this subject. Many different instrumental and intermelodic combinations can be conceived and controllable sound structures can be generated using the approach taken in this study, but the perceptual evaluation of these sounds is an extraordinarily complicated process that appears to reap few immediate benefits. The approach taken in generating the sound masses described in Appendix D may prove to be more compositionally fruitful, although this method is somewhat arbitrary and characterized by trial and error. Also, the evaluation process for fusion effects is entirely subjective when this approach is taken. Nonetheless, this less structured kind of computer-based orchestration has musical possibilities for composers who wish to control the generation of sound masses and fused ensemble timbres, and are willing to experiment freely with sampled sounds. Still, firm guidelines for the generation of FETs can only be established by more systematic means, whether with the aid of music perception test design or some other solid theoretical approach.

The fused ensemble timbre issue is alive, and sounds that qualify can be heard in the work of many contemporary composers. For composers working in computer music, this subject may prove to be increasingly interesting, not only as it relates to the generation of interesting sonic material, but with regard to form-bearing processes (McAdams, 1985). The remaining speculative discussion deals with possibilities for the compositional use of these structures in computer music, purely as interesting sounds as
well as in formal contexts.

A. A Speculative Discussion of FETs and Computer Music.

We encounter a situation in the music of many contemporary composers that reflects an approach to timbre far removed from that of their earlier counterparts. No longer tied to the treatment of timbre as melodic carrier alone, composers now actively engage in the creation of what has been described as timbral objects, that is to say, sounds that are unitary in nature and marked by a particular timbre; indeed, the use of a sound for purely coloristic purposes is common in many contemporary works. All of the composers cited earlier engage in a compositional treatment of timbre that is quite untraditional in nature. Many of the sounds heard in Schwartz's music, for example, seem to resemble the kinds of sounds that one might hear in pure electronic music. Varèse and others have pushed instrumental sonic possibilities nearly to the limit and computer music seems to offer the greatest possibilities for further musical extension. Composers and researchers working in computer music are presently experimenting with diverse approaches to the compositional treatment of timbre and new techniques are constantly being developed. Computer-based synthesis provides the composer with complete quantitative control over sound, but too often the computer musician runs the risk of not being able to see the forest for the trees. Indeed, techniques in and of themselves bear little artistic fruit if they are not wedded to a useful aesthetic. This study has dealt with fused ensemble timbres with the overriding proposition being that these sonic structures are valuable to composers working in computer music. In the author's opinion, this value will be manifest to those composers working in computer music who are interested in
developing techniques that will serve as an extension of traditional instrumental possibilities. As real-time processors become more efficient and powerful, the capability for processing a fused ensemble timbre in a live performance will be of increasing interest. But the emphasis upon this particular kind of sonic structure betrays a bias on the part of the author for what may be best described as a 'fusion aesthetic'. At the risk of presenting jargon, the meaning of this idea will be considered.

If we propose that a technique can be of inherent value to artists then we are assuming that such a technique will serve, in some capacity, that which lies within the domain of the artist (e.g. the creation of beautiful works, communication, etc.). Composers working in computer music must be concerned with the efficiency of 'tools' on a conceptual level, which is to say that useful techniques should allow the composer to achieve controlled effects, perhaps as the result of precompositional thought. One problem in computer music is that there is not always a correlation between technique and aural effect. Too often, composers of computer music are wandering amid a morass of sonic possibilities. This is not to suggest that a common practice can serve all artistic interests; rather, the description of "conceptual tools" will aid the composer who wishes to communicate musically in computer music. Edgard Varèse searched most of his creative years for tools that would satisfy his musical vision. Only toward the end of his life did he come across the means through the electronic medium. Further, he seems to have engaged in a kind of instrumental writing that was "electronic" in nature (e.g. involving treatments of timbre, manipulation of masses and timbral objects). One "conceptual tool" to be proposed here picks up where Varèse left off. The fused ensemble timbre is seen as a means of establishing a connection between two classes of sounds; first of all, those that
era of acoustical origin and secondly, those that are computer-generated. The musical context in which the FET could be presented, is depicted in the following diagram:

![Diagram showing movement in time from Acoustical Sound Domain to Computer-generated Sound Domain](image)

**Figure 6:** Illustration of FET connection.

This diagram refers to an approach wherein movement from one class of sounds to another takes place via a connecting sound mass intended for fusion. This sound mass could have characteristics of both sound classes at the point of its occurrence. It would consist of digitized instrumental tones that might be processed at this point in a number of ways with the aim of resulting in a fused percept. One approach to processing a sound mass involves the phase vocoder, which would support the implementation of a number of digital treatments of the sound, including equalization of perceptually salient amplitude peaks and the complete redistribution of amplitude values. Another treatment might
Involve experimentation with the stretching of partials and/or formants by micro-tones to increase the overall inharmonicity, as has been suggested by McAdams and Serriah (1985). It is possible that a "vibrato" or "jitter" frequency modulation factor might be synchronously applied to the component tones in a sound mass as a means for creating a fused sound (Bregman, 1985). Also, an amplitude modulation factor might be synchronously applied to each instrument for the same reason. One final proposed treatment would involve the addition of inharmonic sounds to a sound mass, essentially relying upon the idea of critical bend, "filling in" the areas of the spectrum where no acoustical activity was evident. The spectral analyses would prove valuable in this endeavor, although this procedure would vary from sound mass to sound mass and would involve trial and error.

When we consider treating the fused ensemble timbre as an intermediary structure between two sound classes, the possibility of discrete, temporally separated relationships between boundary domains versus continuous ones might be explored as well. A listener might be confronted with three distinct sounds, one of acoustical origin, a fused ensemble timbre consisting of processed digitized instrumental tones, and a computer-generated sound derived from the previous two.

This conceptual scheme involving fused ensemble timbres is simple. Within a musical context, it is only as simple or as complex as the composer makes it. This proposition centers mainly upon the presentation of sounds of distinctly different timbres and the establishment of means for connecting them, and even progressing from one to the other. This latter notion relates to the possibility that the FET connection can be more or less dissonant depending upon the overall intervallic content as well as the nature of the
computer processing of this sound. It is possible that the preparation of a relatively more
dissonant sound with resolution to a consonant one, in time, might be carried out;
consequently, the FET depicted in Figure 3 could be highly dissonant in relation to the
subsequent sound. It can be asserted that our approach, although apparently simple at the
outset, is musical in nature and implies formal treatments on a large scale as well as a
local one. The idea that a mass or an FET might have formal, structural significance is
suggested here, as well as the idea of timbral progression in a functional sense. We may
find ourselves once again considering the idea of a timbral continuum upon which
progressive events can take place. Tristan Murail has alluded to this regarding the
relationship of harmony and timbre.

One can progressively separate timbres to create the effect of harmony,
and conversely, progressively fuse harmonic relations until they create
a timbral effect. Sometimes with very little change a quite differentiated
conglomerate can become a single sonic components, their frequency
relations, their quality, make all the difference... Therefore there is a
a harmony-timbral continuum... (Murail, 1984) [Note acoustician's use of
the term "harmony"].

In accordance with this idea, we can envision progressions where movement is from the
sound mass, where sound components are discernible, to the fused ensemble timbre and
beyond to computer-generated sounds. The creation of continuity in such transitions
would be a major undertaking for the individual composer.

The overall endeavor described in this study is in its infant stages. The
possibility of ordering the numerous sonic experiences that may result when computer-
generated sounds are conjoined with sounds of traditional acoustical origins seems
overwhelming. In order to progress within this domain, composers must selectively call
upon empirical processes to aid in the establishment of conceptual tools that will help to
define and govern musical operations. Our exploration of fused ensemble timbres reflects
the kind of assertive attempt to order musical materials that composers must make if
purposeful control is to be achieved in the creation of new computer music. When we
consider the evolution of musical thought, we are confronted with the probability of
encountering what may seem, at times, to be the arbitrary making of compositional
decisions. Through the further development and implementation of some of the ideas
presented here we may learn whether or not these issues are manifestations of a journey
down a blind alley, or significant musical concerns that will prove to be relevant in the
future.

More composers and researchers need to be concerned with the arduous
task of investigating acoustical phenomena such as fusion that have been treated in the
experimental literature and that appear to have compositional implications. They must
also be concerned with the implementation of related approaches and techniques that can be
practically brought to bear upon the creation of works of musical art. In this endeavor,
composers, theorists and researchers must work together.
APPENDIX A: Representative Sound Masses in Varèse's Octandre.

Figure 7: Representative Sound Masses in Mvt. 1 of Octandre.
Figure 8: Representative Sound Masses in Mvt. 2 of Octandre.
Figure 8: (Continued)
Figure 9: Representative Sound Masses in Mvt. 3 of Octandre.
APPENDIX B: Description Of Instrument Tones In Storage With Sample Spectral Analyses.

Note: All pitch Designations follow the U.S.A. Standard.

1. Instrument: Trombone

A. Pitch and file information for tones in computer storage:

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<td>TBFS2</td>
</tr>
<tr>
<td>G2</td>
<td>TBG2 and TBNG2</td>
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<td>TBGS2</td>
</tr>
<tr>
<td>A2</td>
<td>TBA2</td>
</tr>
<tr>
<td>A#2</td>
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<td>TBB2</td>
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<tr>
<td>C3</td>
<td>TBC3</td>
</tr>
<tr>
<td>C#3</td>
<td>TBCS3</td>
</tr>
<tr>
<td>D3</td>
<td>TBD3</td>
</tr>
<tr>
<td>D#3</td>
<td>TBDS3</td>
</tr>
<tr>
<td>E3</td>
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<tr>
<td>Bb4</td>
<td>TBNB</td>
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B. Sample Spectral Analyses.

<table>
<thead>
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<th>Filename</th>
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</thead>
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C. Digital Tape Storage:

1. Normal attack at mp - Entire range (E2 to Bb4)
2. Normal attack at f - Entire range.
3. Normal attack at ff - Entire range.
4. Staccato at mp - Entire range.
5. Staccato at f - Entire range.
6. Staccato at ff - Entire range.
7. Crescendo p to ff - Entire range.
8. Decrescendo ff to p - Entire range.
9. Glissandi - 1/2 step movement up and down - Entire range.
10. Long glissandi - Up and down throughout range.

2. Instrument: Bass Trombone

A. Pitch and File Information for Tones in Computer Storage: None.

B. Sample Spectral Analyses: None.

C. Digital Tape Storage:

1. Normal attack - Entire range.

3. Instrument: French Horn

A. Pitch and File Information for Tones in Computer Storage:

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<td>FHNA4</td>
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</thead>
<tbody>
<tr>
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<td>FHNA4</td>
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</tbody>
</table>

C. Digital Tape Storage:

1. Normal attack at mp - Entire range.
2. Normal attack at f - Entire range.
3. Staccato at mp - Entire range.
4. Staccato at f - Entire range.
5. Crescendo p to ff - Entire range.
6. Decrescendo ff to p - Entire range.
7. Stopped tones - Entire range.
8. Trills - Entire range.

4. Instrument: Trumpet

A. Pitch and File Information for Tones in Computer Storage:

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<td>HANSMB</td>
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<td>D5</td>
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B. Sample Spectral Analyses:

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<td>TRPGS5</td>
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<tr>
<td>B4</td>
<td>HANSBB</td>
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C. Digital Tape Storage:

1. Normal attack at mp - Entire range.
2. Normal attack at f - Entire range.
3. Normal attack at ff - Entire range.
4. Staccato at f - Entire range.
5. Staccato at ff - Entire range.
6. Crescendo p to ff - Entire range.
7. Decrescendo ff to p - Entire range.
8. Trills (1/2 steps) - Entire range.
10. Lip trills - Miscellaneous tones.

5. Instrument: Clarinet

A. Pitch and File Information for Tones in Computer Storage:

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B. Sample Spectral Analyses:

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<tbody>
<tr>
<td>F4</td>
<td>CL</td>
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</tbody>
</table>

C. Digital Tape Storage:

1. Normal attack at mf - Entire range.
2. Normal attack at f - Entire range.
3. Normal attack at ff - Entire range.
4. Staccato at mf - Entire range.
5. Staccato at f - Entire range.
6. Staccato at ff - Entire range.
7. Crescendo p to ff - Entire range.
8. Decrescendo ff to p - Entire range.
10. Trills - Miscellaneous tones.
11. Tremolo - Miscellaneous tones.

6. Instrument: Oboe

A. Pitch and File Information for Tones in Computer Storage: None.

B. Sample Spectral Analyses: None.
C. Digital Tape Storage:

1. Normal attack at mf - Entire range.
2. Normal attack at f - Entire range.
3. Staccato at f - Entire range.
4. Crescendo p to f - Entire range.
5. Trills (1/2 step) - Entire range.

7. Instrument: Oboe d'Amore

A. Pitch and File Information for Tones in Computer Storage: None.

B. Sample Spectral Analyses: None

C. Digital Tape Storage:

1. Normal attack at f - Entire range.
2. Staccato at f - Entire range.
3. Crescendo p to f - Entire range.
APPENDIX C: Spectral Analyses of Instrument Tones.

Figure 10: Short trumpet tone 84.
Figure 11A: Trumpet tone G#5 -- Attack portion.

Figure 11B: Trumpet tone G#5 -- Sustained portion.
Figure 11C: Trumpet tone G♯5 -- Sustained portion.
**Figure 12A:** Horn A4 -- Attack portion.

**Figure 12B:** Horn A4 -- Sustained portion.
**Figure 13A:** Trombone tone E2 -- Attack portion.

**Figure 13B:** Trombone tone E2 -- Sustained portion.
Figure 14A: Trombone D3 -- Attack portion.

Figure 14B: Trombone D3 -- Sustained portion.
Figure 14C: Trombone D3 -- Decay portion.
Figure 15: Trombone tone E4 -- Attack and Sustained portions.
Figure 16A: Trombone tone Bb4 -- Attack portion.

Figure 16B: Trombone tone Bb4 -- Sustained portion.
Figure 16C: Trombone tone Bb4 -- Decay portion.
Figure 17A: Clarinet F4 -- Attack and Sustained portions.

Figure 17B: Clarinet F4 -- Decay portion.
Channel 1
Start time: 2.7500

Figure 18A: Bell tone -- Attack portion.

Channel 1
Start time: 3.0000

Figure 18B: Bell tone -- Steady State portion.
APPENDIX D: Description of Synthesized Sound Masses with Sample Spectral Analyses.

SOUND MASS #1

Filename: YARESE3

Content:

\[ \begin{align*}
&\text{Tpt.} \\
&\text{Tbn.} \\
&\text{Hn.}
\end{align*} \]

Duration: 44 seconds

Derivation: See Mvt. 1, m. 18 -- Cl., Ob., Fl.
**Figure 19A:** Sound Mass #1 -- Attack portion.

**Figure 19B:** Sound Mass #1 -- Sustained portion.
Figure 19c: Sound Mass #1 -- Sustained portion.
SOUND MASS #2

Filename: TBYA41

Content:

Duration: 4.2 seconds

Derivation: See Mvt. 1, m. 20 -- Fl., Ob., Cl.
Figure 20A: Sound Mass #2 -- Attack portion

Figure 20B: Sound Mass #2 -- Sustained portion.
Figure 20C: Sound Mass #2 -- Sustained portion.
SOUND MASS #3

Filename: YARE57

Content:

All clarinets.

Duration: 6.2

Derivation: See Mvt. 1, m. 20 -- Cl., Fl., Ob.
**Figure 21A:** Sound Mass #3 -- Attack portion.

**Figure 21B:** Sound Mass #3 -- Sustained portion.
Figure 21C: Sound Mass #3 -- Sustained portion.
SOUND MASS • 4

Filename: TBYA29

Content:

All Tbars. -- Relative amplitudes varied (.5, .7, .5)

Duration: 4.1 seconds
Figure 22A: Sound Mass #4 -- Attack portion.

Figure 22B: Sound Mass #4 -- Sustained portion.
Figure 22C: Sound Mass #4 -- Sustained portion.
SOUND MASS #5

filename: TBYA31

Content:

All Tbs.

Duration: 4.1
Figure 23A: Sound Mass #5 -- Attack portion.

Figure 23B: Sound Mass #5 -- Sustained portion.
Figure 23C: Sound Mass #5 -- Sustained portion.
SOUND MASS #6

Filename: TBYA38

Content:

All Tons.

Duration: 4.08
**Figure 24A:** Sound Mass #6 -- Attack portion.

**Figure 24B:** Sound Mass #6 -- Sustained portion.
Figure 24C: Sound Mass #6 -- Sustained portion.
SOUND MASS #7

Filename: TBYA39

Content:

All Tbsn.

Duration: 400 seconds
Figure 25A: Sound Mass #7 -- Attack portion.

Figure 25B: Sound Mass #7 -- Sustained portion.
Figure 25C: Sound Mass #7 -- Sustained portion.
SOUND MASS 08

Filename: TBVA35

Content:

All Tbs.

Duration: 4.6 seconds
Figure 26A: Sound Mass #8 -- Attack portion.

Figure 26B: Sound Mass #8 -- Sustained portion.
Figure 26C: Sound Mass #8 -- Sustained portion.
SOUND MASS #9

Filename: TBVA25

Context:

\[\text{All Tbn.}\]

Duration: 4.6 seconds

Derivation: See Mvt. 1, m. 27 -- Cl., Cb., Tbn.
Sound Mass #10

Filename: YARE3

Content:

Top to Bottom: Tpt., Tbn., Tbn.

Duration: 4.5 seconds

Derivation: See Mvt. III, m. 46 -- Tpt., Hn., Hn.
**FILENAME:** TBYA27

**CONTENT:**

```
All Tons.
```

**DURATION:** 4.7 seconds
filename: TBVA28

Content:

Durational: 4.6 seconds

Derivation: See Mv. II, m. 24 -- Tpt., Cl., Ob.
APPENDIX E: Perception Test Results.

TABLE 1: Perception Test Raw Data

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Overall Subject Mean = 2.82
Standard Deviation = 0.63
TABLE 3: Rounded Individual Subject Means

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APPENDIX F: Spectral Analyses of Eight Test Stimuli.

**Figure 27A:** YAFFF -- Attack portion.

**Figure 27B:** YAFFF -- Sustained portion.
Figure 27C: VAFF -- Sustained portion
**Figure 28A:** YAFFP -- Attack portion.

**Figure 28B:** YAFFP -- Sustained portion
Figure 29A: VAFPF -- Attack portion.

Figure 29B: VAFPF -- Sustained portion.
Figure 29C: VAFPF -- Sustained portion.
Figure 30A: YAFPP -- Attack portion.

Figure 30B: YAFPP -- Sustained portion.
Figure 30C: YAFPP -- Sustained portion.
Figure 31A: VAPFF -- Attack portion.

Figure 31B: VAPFF -- Sustained portion.
Figure 31C: YAPFF -- Sustained portion.
Figure 32A: YAPFP -- Attack portion.

Figure 32B: YAPFP -- Sustained portion.
Figure 32C: YAPFP -- Sustained portion.
Figure 33A: YAPPF -- Attack portion.

Figure 33B: YAPPF -- Sustained portion.
Figure 33C: YAPPF -- Sustained portion.
Figure 34A: YAPPP -- Attack portion.

Figure 34B: YAPPP -- Sustained portion.
Figure 34C: YAPPP -- Sustained portion.
LIST OF REFERENCES


McAdams, Stephen 1984. Spectral Fusion, Spectral Parsing and the Formation of


Dreams of Time

for Chamber Orchestra and Tape

D.M.A Composition

Presented in Partial Fulfillment of the Requirements for

the Degree Doctor of Musical Arts in the Graduate

School of The Ohio State University

By

Richard Jordan Smeat, B.A., M.M.

********

The Ohio State University

1986

Reading Committee

Dr. Thomas Wells

Dr. Gregory Proctor

Dr. David Butler

Dr. Elliott Schwartz

Approved by

Dr. Elliott Schwartz

Adviser

School of Music
Dreams of Time
for Chamber Orchestra and Tape
(1986)
Richard J. Smoot

Score in C

Instrumentation

2 Flutes
2 Oboes
2 Clarinets
2 Bassoons
1 Trumpet
1 French Horn
1 Trombone

Percussion:

Timpani
Medium Suspended Cymbal
Vibraphone
Gong
Glock Chimes

DX7 Digital Synthesizer

Violin I and II
Violas
Violoncellos
Contrabasses

Prepared Tape -- 1/4 inch at 7 and 1/2 ips

Accidentals are applied to the note they precede and immediate repetitions only.
PASIONATELY, FASTER