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An investigation of the effects of reed strength on the radiated waveform of a B-flat clarinet

Smiley, William C., Ed.D.

The University of North Carolina at Greensboro, 1986

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AN INVESTIGATION OF THE EFFECTS OF REED STRENGTH ON THE RADIATED WAVEFORM OF A B-FLAT CLARINET

by

William C. Smiley

A Dissertation Submitted to
the Faculty of the Graduate School at
The University of North Carolina at Greensboro
in Partial Fulfillment
of the Requirements for the Degree
Doctor of Education

Greensboro
1986

Approved by

James W. Sherbon
Dissertation Advisor

APPROVAL PAGE

This dissertation has been approved by the following committee of the faculty of the Graduate School at the University of North Carolina at Greensboro.

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ABSTRACT

WILLIAM C. SMILEY. An investigation of the effects of reed strength of the radiated waveform of a B-flat clarinet. (1986) Directed by Dr. James W. Sherbon. Pp. 120.

The purpose of this study was to investigate possible effects of reed stiffness on the radiated waveform of a B-flat clarinet, and to investigate possible relationships between subjective ratings of clarinet tones and spectra produced with reeds of various stiffnesses.

Three reeds were selected by using a Maccaferri reed meter to measure the flex of the reed tip for stiffness. The selected reeds were polished and stored in a Reed-Mate humidity case.

The performer was a symphonic clarinetist and university clarinet teacher. The judges were ten professional clarinetists and six advanced university student clarinetists.

All sound data were collected in an acoustically treated room under controlled conditions. Data were collected for three reed strengths and three frequencies at two intensities. The clarinet frequencies used in this study were F3 (155.56hz), G4 (349.23hz), and F5 (622.25hz), which represent the chalumeau, throat, and clarion registers, respectively.

A Fast Fourier Transform was performed upon each sample. The spectra were examined to determine the number and strength of partials in each tone. The judges

listened through headphones to 18 recorded clarinet tone samples and ranked them using a checklist technic. These data were placed in tables for review. The following results were indicated:

(1) Both even and odd partials were present in all the samples. In some samples, the even partials had greater amplitudes than the odd partials.

(2) The amplitude and number of partials present in a spectrum varied between trials of the same frequency, intensity, and reed.

(3) The fundamental was strongest at both high and low intensities with all reeds for G4 and for F3 with the hard reed. For F5 at low intensities, the fundamental was unmeasurable with the soft reed.

(4) The 2nd partial was the strongest for F3 with all reeds at high intensities and with soft and medium reeds at low intensities. The spectra for F5 at low intensities showed that the 2nd partial dominates.

(5) The 7th partial was generally the strongest for F5 at high intensities.

(6) As reed stiffness increased, the number or partials in a spectrum gradually decreased.

(7) Partials within a tone consistently increased with an increase of intensity.

(8) The number of partials within a loud tone increased with frequency.

(9) Tones ranked high by judges were generally rated high in terms of being free, full, solid, and resonant.

(10) There was some evidence that the clarinet formant varies with the change of register.

The timbre preferences of clarinetists remain subjective and personal. Based on the judges' rankings, partials above a certain number may be undesirable in preferred tones. The information produced by this study should be viewed simply as additional data to be considered when describing the acoustical phenomena of the clarinet.

ACKNOWLEDGMENTS

I am especially indebted to Dr. James W. Sherbon for his valuable direction, support and encouragement throughout the preparation of this dissertation. I wish to thank Dr. George N. Heller for the scholarly advice he provided, and Professor Barbara B. Bair, Dr. Eddie C. Bass, and Dr. Gaylord T. Hageseth for giving freely of their time while serving on my dissertation committee.

To Professor Daryl Coad who found the time from his busy schedule to serve as performer, and to the 16 clarinetists who served as judges, I am sincerely grateful. I would also like to thank Dr. David Soderquist for his assistance, and permission to use the IC lab in the Psychology Department.

My special thanks to the Industry Cluster of North Carolina A & T State University for granting funds to purchase the spectral analysis equipment, and to Mr. William Hill for permission to use the Electrical Engineering Laboratory.

To my mother, Barbara Walker, who continues to support my musical development, I am deeply indebted. Finally, to my wife, Sharon, and children, Erica, Keith, and Carl, I am especially thankful. I could not have completed this work without their support, encouragement, and understanding.

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CHAPTER I

INTRODUCTION

The purpose of this study was to investigate possible effects of reed stiffness on the radiated waveform of a B-flat clarinet, and to investigate possible relationships between subjective ratings of clarinet tones and spectra produced with reeds of various stiffnesses. Discussion of the effects from the interaction of a mouthpiece and a reed is an ongoing subject among clarinetists. There is some agreement among clarinetists that a reed should be matched to a mouthpiece, and that extremes should be avoided. In this study, "stiffness" is defined as the blowing resistance and flexibility of a reed tip, and "thickness" as the quantitative measurement from the front to the back of the cut of a reed, between the tip and the stock (see Figure 1). Adjusting the thickness of the tip of a reed will alter the stiffness. Generally, a thick reed tip should respond with more resistance than a thin reed tip. However, the density of the cane varies so that it is not possible to correlate a specific thickness with a specific stiffness.(Wright, 1969).

The American Clarinet Timbre

The quality of a clarinet tone, often referred to as "timbre", is difficult to describe. For example, Pino (1980) described the German sound as dark, full, compact, and almost harsh. Conversely, the French sound is

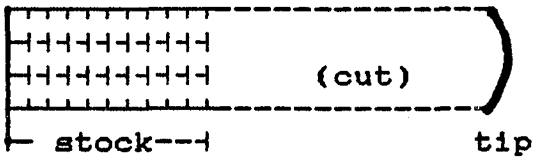

Figure 1. Clarinet reed

described as bright, fluid, clear, at times thin, and "edgy." He described the English sound as mellow and sweet without an "edge" or any great depth. The American clarinet tone is a mixture of the French timbre with German and English influences which may vary with the performer.

In a study to determine verbal descriptors of timbre from acoustically produced clarinet tones, Abeles (1979) used clarinetists, nonclarinetist music majors, and non-musicians to describe 24 recorded clarinet tones using a checklist procedure. The terms selected by Abeles to describe timbre were "mellow, controlled, clear, penetrating, airy, complex, pleasing, and interesting." According to Abeles, American musicians did not associate "pleasing and interesting" with timbre in this study.

Riley (1980) conducted a study to determine whether a systematic method of clarinet tone description could be developed. He identified eight "dimensions" of tone.

(1) mellowness (mellow-harsh)

(2) focus (focused-unfocused)

(3) tone color (bright-dark)

(4) size (full-small)

(5) compactness (solid-spread)

(6) resonance (resonant-nonresonant)

(7) constriction (free-pinched)

(8) clarity (clear-fuzzy)

These "dimensions" were used with a checklist procedure to rate the quality of recorded clarinet tones. Twenty music faculty members, graduate students, and undergraduate music majors were selected to serve as judges. The responses were charted on a "profile sheet" as a graphic representation of tone quality. The following is a list of conclusions made by Riley:

(1) The use of paired opposites (clear-fuzzy) clarifies the description of tone quality.

(2) Since the subjects were from various backgrounds, and since the eight paired-tone descriptions elicited agreement among the test subjects, these eight paired opposites could be the basis of a common vocabulary among the clarinetists.

(3) The profile method avoids judgmental factors; two individuals could agree on how dark, how bright, or how solid a tone is without necessarily agreeing on whether the tone was of superior or inferior tone quality.

Prior to 1900, before scientific developments improved travel between nations, and before recorded sound was readily available, national schools of clarinet performance styles and tonal concepts developed. According to Pino (1980), the main influence on American clarinetists was French, though other styles were blended. He stated that nearly all orchestral clarinetists who gave lessons between 1920 and 1960 taught their students primarily in the tonal concepts of the French clarinetists; those students, in turn, often taught in American universities and they continued to use primarily these same French timbre concepts.

In a study of differences between German and French clarinet tone spectrums, Wehner's (1978) tables of spectrums show that the German spectrum produced slightly stronger partials below the fifth harmonic, and that the French spectrum generally produced slightly stronger partials at and above the fifth harmonic. Backus (1977, pp.118-120) stated that tones with many high-frequency harmonics tend to sound "brighter," and those with fewer tend to sound "darker." This may explain why the French timbre is commonly described as brighter than the German timbre.

Current American clarinetists have had the advantage of tape and phonograph recordings which enable them to hear tone qualities of Europeans and other Americans. Some writers suggest that a unique American timbre has evolved from a mixing of tonal concepts. According to Kireilis (1975) the tone of a clarinetist tends to evolve from attempts to imitate a tone heard in a performance by an artist in concert or from a recording. He theorized that the variance in individual concepts of clarinet timbre is the greatest distinguishing factor of tone quality. Pino (1980, p. 229) suggested that an identifiable American clarinet timbre must be less easily defined than that of either France or Germany, as Americans perform with a variety of tone qualities. Westphal (1985, p. 82) stated that there is no single standard for a good tone on instruments of the clarinet family. He stated that the tone quality of French, German, English and American clarinetists will all be quite different but pleasing. Westphal concluded that national differences can be readily discernible in the tone qualities of clarinetists in spite of influences from diverse schools of clarinet timbre concepts.

The Reed

A clarinet reed, a vibrating element or pulsating source, is one of the factors that determines the quality of a clarinet timbre. Reed instrument performers, especially clarinetists, have complained of being at the mercy of the quality and the cut of cane used to manufacture reeds. The pedagogical texts include many statements about the precarious nature of the reed (Baines, 1975; Pierce, 1984). Unlike flutes or brass instruments that have relatively consistent sound generators, reed instruments require a piece of cane that is constantly changing in its physical characteristics.

Reed Materials and Reed Quality

Some attempt has been made to produce reeds from various materials such as plastic, fiberglass-reinforced plastic, aluminum, and a variety of cane. So far, Arundo donax cane is preferred by most clarinetists and reed manufacturers (Veselack & Nisbet, 1981). Arundo cane requires a special soil and climate for growth, like that found in the Var region of southern France. A possible alternative to improving reed materials may result from the experiments of strenghtening cane fibers with resin-like materials (Locker, Edlefsen, & Williams, 1981).

Over the years, clarinet students have been instructed to judge a reed by its appearance. However, a reed that appears to possess the correct color and texture often produces a disappointing tone quality. Conversely, a reed with a poor visual appearance may perform surprisingly well.

Most reeds will change in response after use. McGann (1976) found that stresses from performance, soaking, and drying rather than from saliva or water, caused deterioration in reed cane. With a precision cut, the quality and consistency of a reed are dependent on the quality of the material from which it is made and the ability of that material to withstand mechanical stresses. Research completed by Locker et al. (1981) has implications that polymer impregnation of reeds may help in the stabilization process. Details of this study are discussed in Chapter 2.

Reed Stiffness

Manufacturers have developed a standard numerical rating system of one to six to indicate the general stiffness of reeds. The number one refers to reeds that are soft and thin, and the number six refers to reeds that are hard, stiff and thick. Reeds rated as two, three, four, or five designate gradations of stiffness between one and six. Reeds of the same thickness may respond with varying resistance to when used in performance. Therefore, some manufacturers identify reeds as having an approximate rating of one and one-half to two, or two and one-half to three. Other manufacturers use adjectives such as hard, medium hard, soft, or medium soft to rate the stiffness of reeds.

Writings in pedagogical texts related to the effects of reed stiffness on a clarinet timbre tend to be stated in subjective terms, or are associated with general observed relationships between a mouthpiece tip opening and a reed's stiffness as described below. Dark, cold, large, small, thin, fat, reedy, and colorless are some of the adjectives used to describe the effect of a reed's stiffness on a clarinet tone. Westphal (1974) provided a typical pedagogical description and response for a variety of reed strengths.

1) Soft reeds are identified by a thin reedy sound; they require little breath pressure for tone

> production, and usually play out of tune.
>
> 2) Slightly hard reeds meet the general criteria for good reeds except that they blow a little hard, or they cause a rough chalumeau tone quality while the clarion register is good.
>
> 3) Medium hard reeds require a greater breath pressure to produce a tone and are somewhat rough in both the chalumeau and clarion registers.
>
> 4) Very hard reeds require an extraordinary amount of wind pressure to produce a tone, and produce a hard, rough, and squawky tone quality.(p. 280)

These terms do not lend themselves to quantification, and cannot be used to describe the phenomenon of timbre accurately. Even when researchers like Wright (1969) use a caliper type of instrument to measure the thickness of a reed at points in thousandths of an inch, the resulting tone qualities are described in subjective terms similar to those listed above. Conclusions expressed in this manner are difficult, if not impossible, to correlate with other studies or replications. Few research studies on reeds present data that identify a relationship between reed stiffness and the radiated waveform of a clarinet tone.

Reed/Mouthpiece Combination

There may be a direct relationship between reed stiffness and the dimensions of a clarinet mouthpiece as related to playing response and timbre.

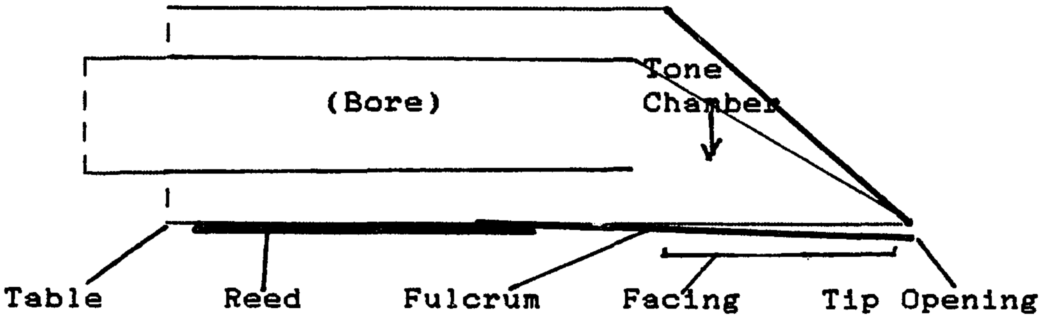

Figure 2. Clarinet mouthpiece

The tip opening--the distance between a reed and a mouthpiece at its tip-- may generally be described as open (wide), medium, or close (see Figure 2). The facing or lay of a mouthpiece--the area that slants away from the reed to the tip--may vary in length and amount of curvature. Usually, a long facing requires a soft reed, and a short facing requires a stiff reed. A wide tip opening requires a soft reed, and conversely, a close tip necessitates a stiff reed. Though the above description seems to suggest that matching a reed's stiffness to a mouthpiece tip opening or facing creates a satisfactory result, pedagogical literature (Stubbins, 1965; Westphal,1974) theorizes that a medium mouthpiece lay and tip opening with a medium stiff reed will produce the "best" results for most performers. Medium is defined as the average dimensions of a mouthpiece tip opening and facing, and a reed rated between a stiffness of two and three.

Need for the Study

Backus (1964c) described the need for research on the clarinet timbre in the following way:

> The detailed harmonic structure of the sound radiated by the [clarinet]--its "tone" in the musician's use of the term--depends in a complicated way on the size, shape, and position of the tone holes, the mass and stiffness of the reed, and other factors. To work out this dependence, both theoretically and experimentally, is the main object of the research on the clarinet, and it turns out to be a difficult problem.

> Much work needs to be done to determine the difference between a "good" and "bad" tone. It may be that all harmonics above a certain number are undesirable. (p. 41)

Backus (1966a) later identified six parameters of a reed that influence the harmonic structures of loud tones sounded on a clarinet. Two of these parameters are related to reed stiffness:

> 1) The stiffness of the reed determines the ease of blowing the instrument.
> 2) The mass of the vibrating tip of the reed, together with the stiffness, determines the resonance frequency of the tip, which influences the higher harmonics of the tone. (p. 1220)

Lanier (1960) acknowledges the problem of varying reed thicknesses in the following statement.

> Clarinetists are aware of differences in tones produced from an instrument employing different mouthpieces and reeds. Many are aware that the variance in the thickness and evenness of the reed cause alterations in its mode of vibration. This in conjunction with changes in the lay and inside taper of the mouthpiece alters the strength of existing partials and may increase or decrease the total number of partials produced, thus causing the timbre of the tone to change. (p. 16)

Additional justification for the study of reeds is provided by Stubbins (1965).

> It can be argued that art is self-sufficient and complete in itself. It should also be said that the materials of art, the colors of the painter, the words of the poet, and the musical tones of the musician are dependent on physical phenomena without which art could not be. Better and more complete understanding of these materials and their uses cannot fail to increase the efficiency of the artistic process and might perhaps give rise to a broader scope of artistic development simply on the basis of the added freedom of the mind which comes about through greater understanding. (p.46)

The physical structure of the clarinet reed has developed through empirical processes with limited support

Focus of Study

The following questions served to focus the research in this study.

1. What difference exists between the spectra produced with reeds of soft, medium, and hard stiffnesses by the same performer, mouthpiece, and instrument?
2. What relationship exists between the spectra of tones produced by one performer with reeds of various stiffnesses and the rating of those tones by trained musicians?

CHAPTER II

REVIEW OF THE LITERATURE

A survey of the literature regarding some of the most common theories of the clarinet timbre indicates that several parameters may influence tone quality. These parameters include (1) the intensity level of a tone, (2) the vibrating mode of a reed, (3) air pressure, (4) the initial transient and decay of a tone, (5) a performer's oral cavity, (6) the ligature, (7) embouchure pressure on a reed, (8) the internal dimensions of a clarinet bore, (9) the interior shape, length, and tip opening of a clarinet mouthpiece, (10) the anatomical structure of reed cane, and (11) the physical characteristics and dimensions of a reed. One theory often cited in literature related to vocal timbre is the formant theory. A brief explanation of this theory and its application to the clarinet timbre will be included under the heading of Clarinet Acoustics. Before considering analyses of clarinet tones under various conditions, it is necessary to review research that is related to such experiments.

General Acoustics of a Complex Tone

A complex tone is composed of a mixture of simple tones of various amplitudes and frequencies. Timbre is determined by the number of, hz of, and amplitude of the individual partials. The number of oscillations during one

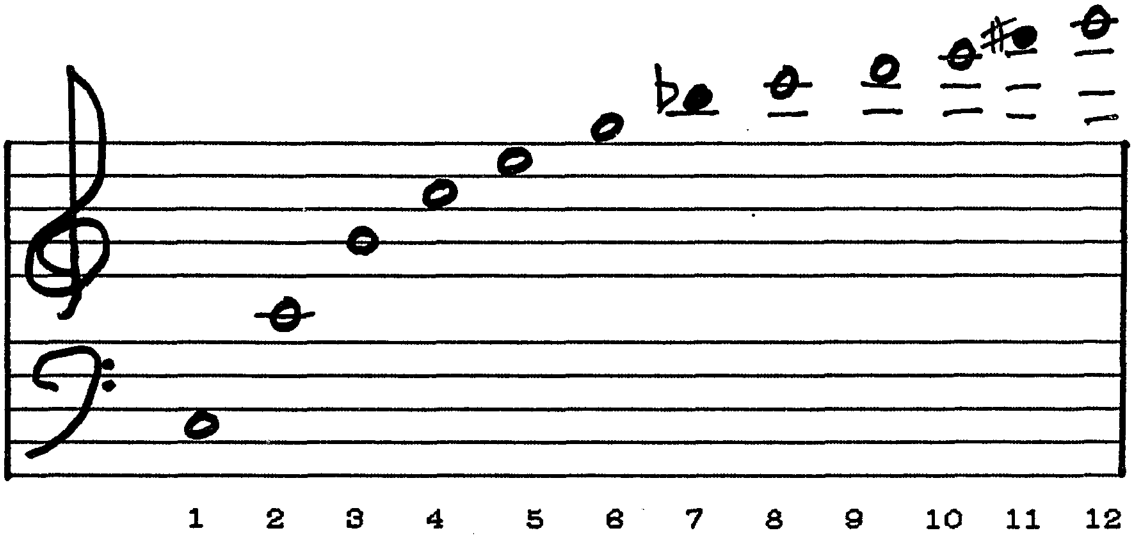

Figure 3. The harmonic series on C3.

The shaded notes represent frequencies that are not in tune with equivalent pitches in the Western tuning system.

second of a simple tone determines the hz which is psychologically perceived as pitch. The envelope for one hz, from start to finish, is called the waveform of the vibration. Partials are integers of one, two, three, etc. times the fundamental hz of the complex tone. The lowest partial may be identified as the fundamental or first harmonic. The remaining partials above the fundamental are identified as the second, third, fourth, etc. harmonics. The total number of partials for a complex tone constitutes the harmonic series (see Figure 3).

Acoustics of the Clarinet

Only the clarinet family overblows a twelfth rather than an octave. This phenomenon is generally described as the result of the clarinet's having a pressure antinode in the mouthpiece, responding acoustically like a pipe closed at that end, and producing only the odd-numbered harmonics. However, reports of research by Blaikley in 1884 (Helmholtz, 1912; Rendall, 1971) indicate that even-numbered harmonics were detected in a clarinet tone. Miller (1931) photographed clarinet tone spectra with an oscilloscope camera and found that the tone contained 20 or more harmonics. Of these, he found that twelve harmonics were important, with the 7th, 8th, 9th and 10th predominating. The 7th harmonic contained 8% of the total intensity, while the 8th, 9th and 10th harmonics contained 18%, 15%, and 18% in that order (p. 33). McGinnis, Hawkins, and Sher (1943) found that the characteristic feature of the chalumeau or low register of the clarinet was that the even harmonics--second, fourth and sixth--have amplitudes much smaller than the odd harmonics--first (fundamental), third, fifth, etc. In the throat register, they found that the 8th harmonic was the most important in their sample, and that the even harmonics began to appear just as frequently and prominently as the odd harmonics above the 9th partial. The even harmonics in their samples became more prominent as the registers moved upward. Chatterji (1952), Das (1931), Ghosh (1938), Parker (1947), and Smith and Mercer (1974) also detected the presence of even harmonics in their analyses of clarinet tones.

Formant theory

One method of establishing a correlation between a clarinet and its sound spectrum is to plot graphically several frequencies for the purpose of defining a formant. White and White (1980) defined the formant of a musical tone as "a frequency band in its sound spectrum where sound energy is largely concentrated" (p. 92) (Figure 4).

Savage (1977) described a formant as "peaks in the spectrum envelope of musical instruments" (p. 183).

According to Backus (1977), the formant theory suggests that, regardless of the frequency of the fundamental, an instrument has a fixed region of

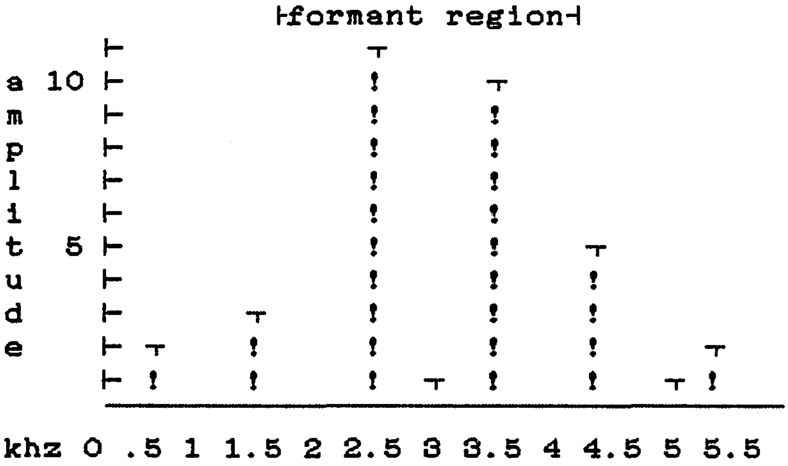

Figure 4. Formant of a hypothetical tone

frequencies in which harmonics or partials of a tone are emphasized. The timbre of an instrument is determined by the location of these formant regions. A clarinet in general has two pronounced formant regions at 1500 to 1700 hz and 3700 to 4300 hz (pp. 118-119).

> One of the astonishing results of studying many sound spectra is the fact that the fundamental frequency that determines the pitch of the note is frequently not the loudest of the harmonics, and it is often relatively weak. As one might suspect according to the principle of formants, the high intensity, upper partials often determine the timbre of the instrument. (White & White, 1980,p. 93)

Miller (1956) studied the harmonic structure of clarinet tones through the use of an audio wave frequency sweep spectrum analyzer and an oscilloscope camera. A comparison was made of tones played on the same clarinet and reed by different subjects. He found the patterns to be more alike in the clarion register than in any other register. The following are four of several conclusions reached by Miller:

1. The formant theory does not sufficiently explain the distribution and amplitude of the partials of the clarinet spectrum.

2. The formant theory does not adequately explain the clarinet timbre and does not identify the cause of the harmonic structure of the spectrums.

3. The use of the same reed, mouthpiece, and instrument by different subjects does not result in identical or closely similar spectrum patterns throughout

the entire clarinet range.

4. The examples of so-called "characteristic" clarinet tone spectrums in some previous research projects are not compatible with the findings of the Miller study. They are "characteristic" only of one subject using a specific clarinet and playing a specific note.

Influence of Intensity Levels and Frequency on Timbre

The complexity of a clarinet waveform is dependent on several factors. Intensity and frequency influence the amplitude and number of harmonics produced for a tone. Waveforms are more complex for tones of high intensity than for tones of low intensity (Backus,1961; 1960). In a study of variations with loudness of the harmonic structure of clarinet tones, Backus (1962b) found that the upper harmonics are reduced as the tone becomes less intense. When describing the harmonic structure of a clarinet tone, he found that specifying the sound level was critical when comparing clarinet tone spectra. Waveforms tend to be less complex at higher frequencies than at lower frequencies, and too large a proportion of high harmonics in the [waveform] may be undesirable (Backus, 1964c).

The intensity level and frequency of a tone are critical factors when making comparative studies of clarinet tone spectra. When collecting data, the sound level, hz, and source to input distance should be specified.

The Vibration of the Clarinet Reed

The oscillation of a clarinet reed was studied by Ghosh (1938). He theorized that "the aperture between the reed and the mouthpiece never completely [closes]." McGinnis and Gallagher (1941), in a study to determine the mode of vibration of a clarinet reed, found that the aperture was open for one-quarter cycle, and closed for the remainder. Backus (1960) found that for intense tones the reed aperture is completely closed for almost half the cycle and almost completely open for the other half. The closed time diminished as the intensity diminished, and the aperture did not close at all for less intense tones. This suggests that both Ghosh and McGinnis may have been correct, depending on the intensity level of the tones in their samples.

Backus (1966a) concluded that the detailed harmonic structures of intense tones sounded on a clarinet depend, in part, on certain physical parameters associated with the clarinet reed. The six parameters he found to influence the tone to some extent were the stiffness of the reed, the mass of the vibrating tip of the reed, the damping of the reed material, the gap between the reed tip and mouthpiece tip, the amount of leakage past the reed in its closed position, and the impact of the vibrating reed against the mouthpiece.

Backus (1960) studied the vibrations of a reed on an artificially blown clarinet. A photoelectric method was used in which light from a source placed at the bell of the instrument passed through the aperture between the reed and the mouthpiece and into a photomultiplier tube whose output was observed on an oscilloscope. He concluded that the end of the reed moved as a unit with no perceptible phase shift from one side to the other.

An earlier 1936 study by Ashoff (cited in Backus, 1960) described a reed as vibrating over the entire exposed length from the ligature to the tip. Ashoff concluded that a reed vibrated at the fundamental frequency between the ligature and the point at which the lip makes contact, with the frequency increasing from that point to the tip, and increasing more at the tip.

In contrast, Backus (1960) found that all parts of the reed that were in motion oscillated in the same manner as the tip of the reed but with an amplitude that decreased from a maximum at the tip to zero at a point about 1.5 cm from the tip. The remaining exposed portion of the reed between this point and the ligature, about 2 cm, did not vibrate. According to Backus (1963a, 1963c), the playing frequency of the clarinet is a little below the air-column resonance , and the reed has a resonance frequency of its own somewhere above 10khz.

Coppenbarger (1970) investigated the behavior of a vibrating clarinet reed utilizing high speed cinematography. He found that the reed vibrates at the same frequency as the frequency of the tone, creating a gap between the reed and mouthpiece from the tip to the lips. He found the wave form of the reed-tip's movement to be a quasi-square wave as a result of the opening and closing speed of a reed. The fastest speed of a reed in this study occurred just before closing, resulting in a small rebound vibration. The dampened reed's natural frequency was between 3300 to 3600 hz.

Gordon (Intravaia & Resnick, 1968, p.53) theorized that a reed vibrates both along its length and from the center out toward each side. His theory was that the response of a reed would improve if the reed were adjusted to vibrate more freely along its length and less from center to sides.

Scott (Intravaia & Resnick, 1968, p.52) theorized that the segment of the reed which is in free vibration is from the fulcrum (the point on the mouthpiece lay where the reed and mouthpiece begin to separate) up to the tip; below that point, the reed is stationary.

In a study to develop a technique of adjusting clarinet reeds that would not disturb the basic structural balance of the reed, Intravaia and Resnick examined the vibrational pattern of a reed by replacing the clarinet bell with a suction device. They found that the center of the reed tip appeared to vibrate less, or more slowly, than the corner, thus producing a curved appearance to the reed while in motion. Encouraged by Scott's theory, they cut a groove into the vamp of a reed at the fulcrum and found that the entire reed tip remained parallel to the mouthpiece tip when in motion. They concluded that results were more successful with the cutting-in-the-groove technique than with other known methods of reed adjusting.

Stubbins (1965, pp. 61-68) described the oscillation of a clarinet reed using a theorem known as Hooke's law--the restoring force is equal to the displacement force. He theorized that the natural spring action of the reed is strong enough to cause it to return to its primary position of rest, and to continue beyond this point. The reed is then overcome by the inertia of its mass, and is then returned by the embouchure, or lip pressure of the player, to its primary position.

Backus (1963b) disagreed with Stubbins' conclusions about the oscillation of a reed. He found that the reed was in contact with the mouthpiece for almost one half cycle. The maximum displacement of the reed from the mouthpiece during the other half-cycle was always less than the displacement with the blowing pressure removed. Backus found that the reed did not oscillate back and forth about the equilibrium position, and that it did not return completely to the equilibrium position while sounding a tone. In Coppenbarger's (1970) study, the reed did not rebound beyond a straight line. Backus (1966b) found that due to usual reed warping, the reed does not completely close during that part of the cycle that it is in contact with the mouthpiece. Backus found no evidence that a relationship exists between the quality of a clarinet tone judged by ear and whether or not the aperture of the reed closes completely.

The oscillation of a clarinet reed varies between and within studies. Recent studies conclude that a clarinet reed generally does not rebound beyond its equilibrium point and may not always return to its starting point while sounding a frequency. A clarinet reed oscillates at the same frequency over the entire area that vibrates (Backus, 1960). However, there is some disagreement about the area and amount of a reed that vibrates, and whether or not a reed oscillates at the same frequency as the sounding tone. Intensity is a factor in whether or not the reed tip closes completely when in contact with the mouthpiece. There is no evidence that the extent of a reed tip closing when in contact with a mouthpiece has a significant effect on timbre.

The Ligature and Butt of a Reed

The effect of a clarinet ligature on the vibrational characteristics of a reed is a topic of concern among clarinetists and pedagogical texts. Preferences for ligatures vary among clarinetist as much as there are varieties available. Typical ligatures are made of metal, plastic, rubber alloy, leather, and string. Some ligature designs include several strips, one single strip, posts that touch the reed only at specific points to allow for maximum vibration, fasteners above the reed, and fasteners on the opposite side of the mouthpiece from the reed. Stubbins (1965) wrote the following about ligatures:

> The lower portion of the clarinet reed acts only as a handle to support the vibrating part of the reed. Ligatures which claim the distinction of "allowing the reed to vibrate more freely" are making a ridiculous statement with respect to the mechanics of sound production on the clarinet. A ligature is designed to hold the reed firmly on the mouthpiece lay, without distortion in such a way that it will act as a vibrating blade at its thin, shaped end. It is for this reason that string is best used as a clarinet ligature. The great damping potential of the string acts as a perfect foil for any noise quotient of the reed's action which may be transferred along the reed fibers from the vibrating tip to the heel.(p. 95)

Stubbins' statement is a contradiction as he assigned no importance to a type of clarinet ligature, and then proceeded to describe the best type of ligature to use. One may conclude that tradition is more influential in a clarinetist's choice of ligature than research.

Stein (1958, p6.) concluded that the "ligature can ruin reed response and reed life immediately by pinching the cane on the sides." He theorized that "this [pinching] results in a concavity which destroys free vibration"

Palanker (1976) stated that the ligature can add or detract a great deal from the refinement of a clarinet tone. He theorized that the ligature is important in terms of how the reed will vibrate, and that this response will vary greatly from ligature to ligature. The standard response that Palanker uses for comparison is the response of a reed when held on the mouthpiece with a thumb instead of a ligature. Palanker described the virtues of one ligature as follows.

> The Gigliotti Ligature is made of a plastic or rubber alloy. It has ten strips around the entire ligature which are the only points of contact on the reed and mouthpiece. It produces a bigger, more vibrant tone, without spreading. The reed seems to vibrate more but enables the tone to remain dark and centered. This ligature is good for eliminating a tubby, dead, fuzzy tone.

The reed butt--the stock end where bark remains--(Figure 1), has been manufactured with grooves cut in it for the purpose of increasing the vibrational characteristics of a reed. Many clarinetists recommend to their students that the sides of the butt be of equal thickness. Backus (1964c) concluded that the shape and thickness of the butt of the reed, as well as the kind and position of a ligature, have no effect on the tone of a clarinet. Much of the pedagogical literature (Stein, 1958; Tos'e, 1962; Rendall, 1971; Willaman, 1954) tends to disagree with Backus' conclusions. More conclusive evidence from research may be required to support or overcome tradition.

The Importance of Attacks and Releases

In a study describing the perceptual effects of three types of data reduction--amplitude, frequency, and timing--Charbonneau (1981) concluded that amplitude was probably the most sensitive dimension of all sound. He found that delays existing in natural sounds between the starting or ending times of all partials were important but probably not critical for the identification of timbre. He found that the harmonics of a tone began and ended at different times for the same frequency.

When Elliott (1975) presented samples of unaltered instrumental tones to subjects, they could correctly identify those instruments a significantly (p=.05) greater number of times than when samples of the same instrumental tones were presented with the attacks and releases removed. However, he found that the clarinet, oboe, and trumpet tones were correctly identified a significant (p=.05) number of times, even when attacks and releases were removed from examples of those tones. His conclusion that attacks and releases may be significant factors in making judgments of instrumental timbre may not apply to the clarinet.

Embouchure and the Oral Cavity

Lip Pressure

Lip pressure on a reed has some effect on frequency, and gives a performer some control over intonation, according to Backus (1960, 1961). The playing frequency of the clarinet is below the air-column resonance by a small amount that varies in a linear relationship with the reed opening and the reed damping. He concluded that the rise in frequency from increased lip pressure on the reed is the result of a smaller reed opening rather than any change in the resonance frequency of the reed itself. Backus (1963c) found a direct relationship between the threshold blowing pressure and the reed opening and reed stiffness. He found that reed damping caused no variation, suggesting that the condition of a player's lip should have no effect.

Coppenbarger (1970) found that the embouchure pressure required to sound the clarinet reduced the mouthpiece-reed gap 43% from its nonpressure measurement. He found that in a steady tone, the tip of the reed's excursion was further reduced (a Bernoulli effect is created), which constantly pulled the reed toward the mouthpiece lay. In this study the gap between the mouthpiece and reed closed completely about 40% of a cycle, and never more than 45% of a cycle.

Air Pressure and Tone Quality

In a study of the effects on tone production of reed length, air pressure, and force placed on a reed, Jensen (1955) found that amplitude increases with air pressure to the point where the air pressure becomes sufficient to force the reed tip to remain in contact with the mouthpiece. In addition, he found that frequency increases with force and decreases with reed length; that frequency increases as the reed tip is forced to vibrate closer to the mouthpiece; that the power of odd partials increases with air pressure and decreases with embouchure force; that the 3rd, 6th and 7th partials increase with reed length; and that the 2nd partial decreased in power as force was added.

Backus (1964a) found that air flow may have an effect on intonation of the clarinet, as much as 25 cents.

Mooney (1968) studied the effect of the oral cavity on the clarinet timbre, and found that air pressure influenced the pitch of a tone. Three of his conclusions are listed below:

1. Clarinetists used slightly different air pressures in the mouth to produce tones at the same intensity and frequency.

2. Air pressure decreased as the high register was approached.

3. The direction and speed of the air flow had a

consistent effect on the reed.

Research conclusions indicate that the the speed and direction of air flow may have an effect on the timbre and intonation of a clarinet.

The influence of the oral cavity

Stauffer (1968)observed 35 highly skilled musicians in the United States Navy Band and found a consistency of embouchure adjustments among the performers. He concluded that it was necessary to vary the size of the mouth cavity for proper artistic tone production in high and low registers. His conclusions were based on individual and group subjective judgments that embouchure placement, as equated with vowel formations, is related to the ease and quality of sound production in high, middle, and low tones in several reed and brass wind instruments.

Mooney (1968), in a study of the influence of the oral cavity on a clarinet tone, stated that the position of the tongue in the mouth has an influence on tone quality and pitch. He found that the position of the tongue which gives the best tone quality and pitch for the low register seemed to compare to a high arched back vowel position such as /u/, as in "boot." The position of the tongue which gave the preferred tone quality and pitch in the high register was compared to a low arched, front vowel position such as /a/, as in "father."

Lawson (1974) conducted an investigation to determine whether alteration of the size and shape of the oral cavity influences the radiated waveform of the clarinet. He changed the size and shape of an artificial oral cavity, while all other known variables were held constant. He concluded that the resonance in the oral cavity is not important to the radiated waveform of a clarinet, as many performers, teachers, and acousticians believe. Lawson also found no evidence to support the theory that the direction of air flow against the reed is important to tone quality.

Mouthpiece and Body

Mouthpiece materials

McCathren (1959), in a study of mouthpiece materials, used mouthpieces made of crystal, plastic, wood, and hard rubber to produce tones. To include all registers in his sample, he used the four "G"'s of a clarinet. A tone produced by a hard rubber mouthpiece was accepted as the most desirable because it had the strongest fundamental, and a greater number of stronger partials. He found the "49th partial" in the tone produced on the hard rubber mouthpiece in contrast to finding the "26th," "31th," and "33rd" partials in the tones produced by crystal, plastic, and wood mouthpieces. No details were given in reference to the "49th" partial. McCathren concluded that the upper partials have much to do with the carrying power of the clarinet tone as well as its brilliance and color, and that the hard rubber mouthpiece was superior to those made of wood, plastic, or crystal.

Clarinet materials

Lanier (1960) analyzed tones produced with a mechanical embouchure on clarinets made of ebonite, metal and wood. He used a sound-level meter and harmonic analyzer to produce photographed spectra. Lanier concluded that the wooden instrument was a "better" resonator in that it supported a greater number of partials for the tones open G and low C on a clarinet. However, the differences in timbre of tones produced from metal, ebonite, and wooden clarinets were not recognizable by ear.

Parker (1947) and Backus (1964c) found no evidence to support a preference for a specific type of material in the construction of a clarinet body.

Mouthpiece Bore

Wehner (1963) analyzed the interior shape and size of clarinet mouthpieces to determine their effect on intonation and tone quality. He found that the "best" intonation resulted when the mouthpiece bore size was identical with that of the clarinet used. The frequency increased as the mouthpiece bore size increased, and conversely, the frequency became lower as the mouthpiece bore size decreased below that of the clarinet used. Wehner found that a mouthpiece bore length of 2.125 inches was "best." In addition, Wehner concluded that (1) the bore taper size should be between 0.030 of an inch and 0.050 of an inch; (2) the desirable tone chamber sizes are between 0.045 of an inch and 0.105 of an inch; and 3) The "best" tone quality resulted with a mouthpiece tone chamber depth size of 0.525 of an inch, and a tone chamber taper size of 0.073 of an inch.

Ferland (1982) theorized that the clarinet reed is only one part of a tone-generating organ, the others being the mouthpiece, the embouchure, and the air column. The required air pressure for the production of a given tone on a clarinet will vary with mouthpiece specifications, embouchure characteristics, and reed strength making each of these variables interdependent. Instead of creating an infinite number of variations in mouthpieces and reeds, Ferland, Strouf (1975) and Bonade (Ferland, p. 48; Wehner, 1984) suggest that the choice of a mouthpiece and type of reed should not be made to adapt to a faulty or undeveloped embouchure, but designed solely for acoustical, technical and aesthetical considerations. Strouf concluded that players in major symphony orchestras tend to use mouthpieces normally referred to as "medium." Bonade concluded that any embouchure can be fitted with a "medium" lay and opening of mouthpiece.

Anatomical Structure of Reeds

Reed materials

Some of the materials from which clarinet reeds have been made are plastic, fiberglass-reinforced plastic, hard aluminum, and Arundo donax cane. These materials are soft, stiff, and very stiff, respectively, as related to cane. Backus (1963a) in a study of poor tones found that the soft plastic reed produced more harmonics above the 9th partial, and that the reeds of harder materials produced few harmonics above the 9th partial. The cane reed in his study produced the preferred clarinet tone. He concluded that the production of harmonics above a certain number may be undesirable.

Cell and tissue

Veselack (1979) made microscopic studies of clarinet reeds and living Arundo culms [jointed stems] to compare cell and tissue differences, and to identify possible relationships which may exist between anatomical structure and playability of reeds. She found that "good" reeds contained 1) more twisted vascular bundles in the fiber band; 2) larger radial diameters and larger tangential diameters of vascular bundles; 3) thicker fiber caps and thicker fiber bases on vascular bundles; 4) fewer incomplete fiber rings around the vascular bundles; 5) fewer incomplete fiber rings with breaks lateral to the xylem [woody, supporting and water conducting tissue]; 6) smaller radial diameters and smaller tangential diameters in cells of the ground parenchyma [tissue composed of soft, unspecialized, thin-walled cells]; and 7) a higher percentage of lignified [wood like] cells in the cortex region. With the exception of twisted vascular bundles in the fiber band, Veselack found these plant characteristics to be the result of the growing process. She concluded that "good" reeds are cut from areas of the internode that are adjacent to [joints], and are cut from Arundo culms that are older than culms from which unusable reeds are made. Wright (1969) considered such an investigation to be of value only to persons who plan to purchase a large quantity of raw cane in France, because the information cannot alter the quality of reeds already purchased.

Locker, Edlefsen and Williams (1981) investigated the problem of stabilizing reeds against deterioration. The microstructure of new cane, used cane, and a plastic oboe reed was examined by scanning electron microscopy. They found that reeds deteriorate from physical weaknesses and mechanical stress rather than from the acids, bacteria, and enzymes present in saliva. The researchers used a silicone, resin material in a vacuum and pressure treatment to stabilize the porous texture of cane, and to maintain the structure of a reed in its wet performing condition. They concluded that this method provided some stabilization of cane material, and that no differences in tone quality of the treated reeds were detected by ear.

Selection of a Reed

Clarinet performers and teachers are in general agreement about factors that should be considered in selecting a clarinet reed. The following list of factors is taken from Intravaia and Resnick (1968).

1. The table of the reed at the butt end must be flat.

2. The vamp should be smooth, without raised or rough fibers.

3. The beginning of the vamp, at the shoulders, should be the same distance from the tip on each side.

4. The length of the vamp should cover the "window" of the mouthpiece (the opening of the facing).

5. Against artificial or natural light, the reed fibers should be evenly spaced, straight, close together, and balanced. Some performers prefer the fibers to be visible to the end of the reed tip; others prefer a clear reed tip of about 1/16 inch.

6. From a side view, the stock (sides of the reed from the butt end to the vamp) should be straight; the taper of the sides begins at the vamp.

7. The height of the arc at the butt end should be equal at each side.

8. There seems to be agreement that the reed color definitely should not be green. Some prefer "white" cane,

others prefer "golden" cane, while for some brown specks are most suitable. Grey, dark blotches are a hindrance to proper reed performance. A check for properly aged cane is to dip the butt end of the reed in water, or soak it in the mouth. If the cane is aged, an orange-brown arc will appear at the butt end.

9. There should be a balance between the two sides of the reed. A check on this characteristic may be made by playing with the mouthpiece tilted down (first on one side, then on the other), on the lower lip. If one side of the reed is found to be weaker than the other, the weaker side should be moved a fraction of an inch toward the edge of the mouthpiece (that is, off center).

10. The "heart" of the reed should be in the center of the vamp. This can be determined by examining the reed against strong artificial or natural light.

11. The tip of the reed should be even in strength and free of splits or hard spots. These points can be checked by bending the wet reed very gently against the thumbnail. Uneven or hard spots may be removed by scraping them with Dutch rush or silicon carbide paper.

Westphal (1985, p. 256) concluded that the Vandoren reed has been the standard against which all single reeds have been measured for many years, and that the style of vamp used on these reeds is generally accepted as being the "best."

Reed Thickness

Intravaia and Resnick (1968) made measurements in thousandths of an inch of medium-strength reeds from six different brands. Their measurements indicate that although a similarity exists in the proportionate thickness among brands, there is a slight variation in overall thickness.

Wright (1969) conducted a study based on the assumption that preferred reeds have similar dimensions of thickness at predetermined points, and that these similarities are measurable. He used a caliper type of device calibrated in 1,000ths of an inch to measure thickness. Twenty-five specific points on the reed were measured. Reeds were measured while wet to avoid differences of .002 inch and .003 inch between wet and dry reeds. The tip of a wet reed remains flatter than a dry reed. Wright found that reed thicknesses changed drastically during the first week of playing, and that reeds left to dry after soaking with saliva change more than reeds that were soaked in water. He found the measurable changes to be more pronounced toward the shoulder. Wright suggested that this may explain the phenomena of reeds that play well at first, but perform poorly several weeks later. In addition, he found the area where the reed breaks away from the mouthpiece to be crucial. This possibly relates to the findings of

Intravaia et al. (1968), which were based on Scott's theory. However, Wright recommended that adjustments in thickness be made to multiple areas of the reed to improve performance by making the reed conform with average measurements derived from "good" reeds. Intravaia and Resnick recommended scoring the reed only at the point of the fulcrum. Wright found that thickness and density could not be correlated satisfactorily by touch, sight, or measurements.

Ferland (1982) conducted a survey among symphonic clarinetists and found that most performers used a reed of medium strength. He concluded that clarinetists who used reeds rated at a strength of 4 or 5 "scraped them a lot." Ferland theorized that a reed should be matched to the mouthpiece, and that a clarinetist should not be too dogmatic about the reed strength that he starts out with, because it is the end product that is important.

Measurement of Reed Strength

According to Spratt (1956; p.13), some manufacturers control the stiffness of their reeds by the amount of the tip they cut off. Spratt and Westphal (1985) described testing the strength of a reed by checking the tip and sides with a finger for its flexing resistance. The Maccaferri Reed-O-Meter is a device that measures the stiffness of a reed in terms of a reed's flexibility. A reed is inserted into a slot of the meter, pressure is applied against the reed and a gauge indicates the measured amount of resistance on an interval scale. The French American Reeds Manufacturing Company, Inc. uses this device to grade the strength of their reeds.

Summary

Though a clarinet is generally described as responding acoustically like a pipe closed at one end, producing only the odd-numbered harmonics in its tone, many studies of the clarinet tone spectrum have produced evidence of even-numbered harmonics. The chalumeau register comes closest to being void of even-numbered harmonics. Even-numbered harmonics tend to become more prominent as the registers move upward. This is important in explaining why the formant of a tone may change with frequency or register.

Comparisons of clarinet waveforms from different studies, or from waveforms produced by different performers require that the intensity level be specified. Tones of low intensity are not as complex as tones of higher intensities produced on the same instrument by the same performer. The lack of specifying intensity levels may be a factor in the lack of agreement among researchers as to how the reed oscillates on a clarinet mouthpiece or how spectra differ. A review of the studies did not reveal any evidence that the vibrational mode of the reed produced audible differences in the clarinet timbre.

Although many clarinet instructors and manufacturers insist that ligature designs have a direct effect on the quality of a clarinet tone, there is currently no scientific evidence to support this conjecture. Clarinetists traditionally prefer hard rubber mouthpieces and grenadilla wood bodies for their instruments. While some research data support the choice of a hard rubber or ebonite mouthpiece, research does not provide conclusive evidence that one material is superior to another in the construction of a clarinet body.

Both air pressure and lip pressure against a reed have some effect on frequency. This allows a player some control in adjusting intonation during a performance. However, the direction of the air flow and the size and shape of the oral cavity may be less important as factors influencing tone quality than once believed.

The initial transient and decay components of sound do not seem important in identifying a clarinet tone. There is some evidence from research on synthesized sound that amplitude is probably the most critical dimension of any sound.

The material preferred by clarinetists for making clarinet reeds is Arundo donax cane. Other materials experimented with in reed construction produce tones that are generally unsatisfactory to clarinetists. Reeds made from Arundo cane tend to become thicker following initial soaking and use, which may explain the differences in playing response over a period of time. Experimental testing of polymer impregnation of resin-type materials on oboe reeds may provide a method for stabilizing clarinet reeds.

Clarinetists generally agree about the physical characteristics and structural balance of a reed that will perform satisfactory. A seasoned reed that is not green in color or marked with grey or dark blotches, and that is balanced on both sides should be considered for performance on a clarinet. However, the use of microscopic reed inspection may not be of practical use to the clarinetist unless large amounts of cane are purchased for reed making. Cane already purchased for reed making can not be altered; therefore, such an inspection is of value only when made prior to the initial selection of cane for reed making.

The difficulty in determining the density of a reed makes it difficult to correlate thickness and stiffness. The accepted method for determining reed stiffness is to measure the flexing resistance. Thickness dimensions of reeds are generally more important for reed making than as a determining factor in reed stiffness. Adjusting the stiffness of a clarinet reed by cutting a groove in the reed at the point where it breaks away from the mouthpiece may be preferable to making multiple adjustments so that a reed will conform to a thickness standard.

Most clarinet authorities agree that a medium stiff reed on a mouthpiece with a medium lay should provide the "best" results for clarinetists performing in the American tradition. Several studies conclude that the "best" intonation and tone tend to result from a mouthpiece with a bore that matches that of the clarinet used.

Pedagogical literature (Westphal, 1985) cites tendencies of music teachers to start beginning clarinet students with soft reeds, and then encourage the students to increase reed stiffness with embouchure development and experience. A current search of the literature did not yield studies that describe the effect of changes in reed stiffness.

CHAPTER III

PROCEDURE

The focus of this study was to investigate possible influences of reed stiffness on the radiated waveform of a Bb soprano clarinet. A spectral analysis of clarinet tones produced with reeds rated as soft, medium, and hard was plotted. These data were studied to identify possible influences of variations in reed stiffness on the individual partials of each tonal spectrum. A secondary area of study included an investigation of the timbre preference of tones produced by variations in reed stiffness.

Selection and Preparation of the Reeds

Three French-cut, Vandoren reeds made from seasoned Arundo donax cane were selected from factory-sealed boxes of ten reeds each, using the following procedure:

1. Each reed was judged for flatness, a lack of green or grey color, straightness of grain, length of vamp in relation to the mouthpiece window, and equal thickness on each side of the butt.

2. The vamp and back of each selected reed was polished with #600 silicon sand paper to seal the fibers and remove any roughness.

3. The reeds were soaked in water, allowed to dry for 24 hours, and then repolished.

4. The researcher selected a group of four reeds from each of the three strength categories using a Maccaferri reed meter, and labeled each reed according to a stiffness rating. A meter reading of "2" was classified as soft, "6" as medium, and a reading of "10" was classified as hard.

5. Three reeds--one soft, one medium, and one hard--were selected from the three groups for use in the study. The selection was based on the the stiffness standard listed in item 4.

6. After the final selection, the test reeds were stored in a "Reed Mate" humidity case which maintained a constant moisture level.

Selection of the Study Participants

The performer was Daryl Coad, former clarinetist with the New Orleans Symphony, current clarinetist with the Greensboro symphony, and clarinet instructor at the University of North Carolina at Greensboro.

The judges were ten professional clarinetists and six advanced university student clarinetists recommended by their clarinet teacher.

Experimental Testing

The Physical Environment

The Industrial Acoustics Company (IAC) sound isolation room, located in the Psychology Department of the

University of North Carolina at Greensboro, was used to collect the tone samples. This facility is a double-wall (room-within-a-room) construction with two housings constructed of 4 in. (102 mm) thick modular panels, separated by a 4 in. (102 mm) air space. The Noise-Isolation-Class (NIC), a single number rating system for noise-reduction characteristics, is 75. The Inner room floor floats on vibration isolators, and the outer wall rests on the area floor. Internal dimensions of the room are 10 feet in width, 6 feet and 6 inches in height, and 16 feet in length.

An Audio Technica Model ATM 63 microphone, a Boss B-12 digital tuner, a Realistic #33-2050 sound level meter, and a Pioneer 1020L reel-to-reel tape recorder set at 7 1/2 ips was used to record the tones on low noise, high output 1.5 mil tape (See Appendix A).

The performer sat during the performance to maintain a consistent height and distance from the microphone. The distance from the clarinet bell to the microphone and the sound level meter was 18 inches to provide a consistent point of reference. The tone holes were directed toward the microphone. A manuscript of the performance tasks, a digital tuner to control for a constant frequency, and a sound level meter to control the intensity level was placed in a location visible to the performer.

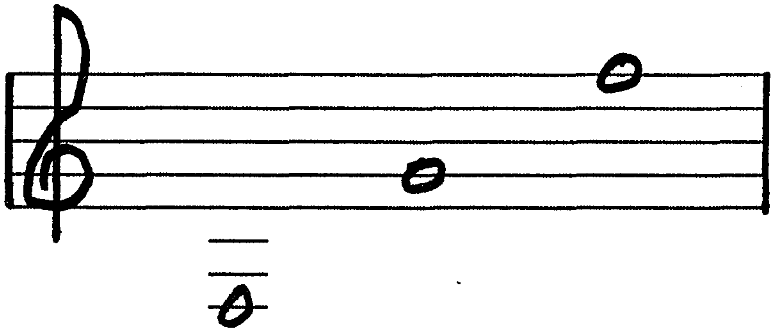

Figure 5. Tones performed on the clarinet

Reed No. 1

Frequency	Trial #1		Trial #2		Trial #3	
155.56hz	70db	84db	70db	84db	70db	84db
349.23hz	80db	90db	80db	90db	80db	90db
622.25hz	78db	94db	78db	94db	78db	90db

intensity (2 levels perceived as soft and loud)
frequency (3 levels; F3, G4 and F5)

Figure 6. An example of the testing procedure for one reed

			REED#1 MRSR*=2			REED#2 MRSR=6			REED#3 MRSR=10		
PITCH	Frequency	Intensity*	Trials			Trials			Trials		
Chalumeau											
F3	155.56hz	70db	1	2	3	1	2	3	1	2	3
F3	155.56hz	84db	1	2	3	1	2	3	1	2	3
Throat											
G4	349.23hz	80db	1	2	3	1	2	3	1	2	3
G4	349.23hz	90db	1	2	3	1	2	3	1	2	3
Clarion											
F5	622.25hz	78db	1	2	3	1	2	3	1	2	3
F5	622.25hz	94db	1	2	3	1	2	3	1	2	3

*Maccaferri Reed Stiffness Rating

**Sound Level Meter Set at "A" Weighting

Figure 7. An example of the design for data collection

Intensity Levels for Sample Frequencies

Clarinet Pitch	Frequency	Low Intensity	High Intensity
F3	155.56hz	70db*	84db
G4	349.23hz	80db	90db
F5	622.25hz	78db	94db

Selected Decibel Levels

*"A" Weighted Scale

Figure 8. Decibel levels

Data Collection Procedure

The performer played three frequencies, three trials each, at two intensity levels on each of the three reeds for a duration of six to eight seconds each-- a total of 54 tasks (see Figure 7). This produced data for three reed strengths, and three frequencies, at two intensities.

The frequencies used in this study represented the chalumeau, throat, and clarion registers of the clarinet. Specifically, the clarinet frequencies F3 (155.56 Hz), G4 (349.23 Hz), and F5 (622.25 Hz) were used. The notes that represent these frequencies are shown in Figure 5.

Prestudy trials of performing the three selected tones on a clarinet while viewing a sound level meter at a distance of 18 inches indicated that the perceived decibel levels for high and low intensities vary with frequency. It was concluded that to obtain the appropriate decibel level differential for each intensity and frequency, three separate trials should be performed for each subjective level of loudness, and averaged. The results of these trials are listed in Figure 8.

Judges Ratings

The group of sixteen judges listened to 18 recorded clarinet tone samples and ranked them as to tonal quality. To control for serial effects, the tones were randomized by producing three test tapes so that three possible order variations were presented to three groups of five judges. Five headphones pretested to ensure identical output specifications were used to reduce the influence of ambient noise. Each judge received identical instructions for ranking the tones. To facilitate the rankings, a checklist technique based on the findings of Riley (1980) was used to collect the data (see Appendix C). A mean score of "1" was considered superior to a mean score of "5."

The judges' evaluation scores were viewed and compared to spectral analysis data to identify possible associations between these data. The mean score for each item of the judges' profile sheet and a composite mean score were computed and presented in a table for each tone rated. The tones receiving the superior ratings were described in terms of the number and strength of partials present in the radiated waveform of a frequency at a specific level of intensity.

CHAPTER IV

ANALYSIS OF DATA

A spectrum constitutes the representation of an analysis of a tone into its constituent harmonics or partials. The quality of a periodic complex tone depends mainly on the relative amplitudes of its partials; therefore, a tone may be characterized by a diagram of its harmonics (Backus, 1977, 115). In this study, the amplitude of partials present in a radiated waveform represented the dependent variable. The measurement of amplitude is discussed below. The variables of instrument, mouthpiece, ligature, frequency, and intensity were held constant. Reed strength was the independent variable.

A Fast Fourier Transform was performed upon each sample from which the scope program plotted the amplitude of the various frequency components of a waveform. The data produced by the spectrum analyzer were plotted in an x - y format with a dot matrix printer. The spectrum for each frequency was printed on an individual chart with the partials plotted along the horizontal axis. The amplitude for each partial was plotted along the vertical axis.

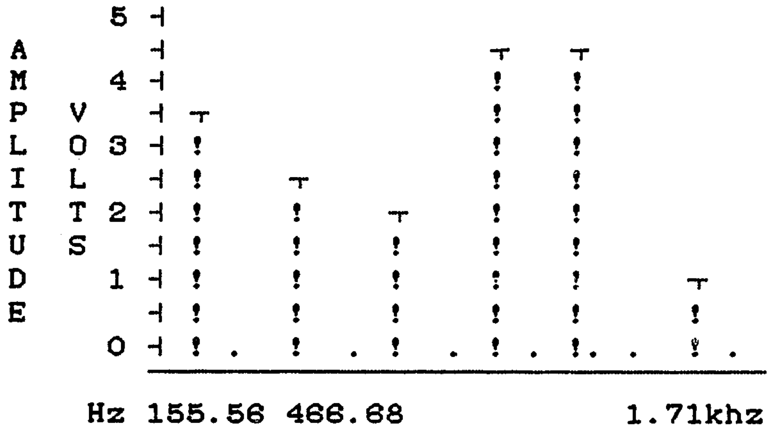

Figure 9. An example of the graphic representation for a tone

The range of measurements for amplitudes was 0 to 5 volts as in Figure 9. The spectra were examined to determine the number and strength of partials in each tone investigated. These data were placed in tables for review.

Quantification of the Data

The mean score for each individual partial, from three trials, produced under identical conditions of reed strength, intensity, and frequency was computed by dividing the sum of amplitude volts by the number of trials. The voltage rating for each partial and the mean volts for each of the three trials were placed in a table for visual examination. The percentage of each partial in relation to the fundamental was also computed, and the data placed in a table.

The mean score for each item of the judge's profile sheet and a composite mean score were computed for each of the three groups of judges. Data from the three groups were used to compute mean scores for an overall ranking of tones and listed in a table.

Observations and Results

The observations that follow are based on a visual examination of the data represented in tables from spectrum analyses and from the judges' rankings of tones.

Differences between the Three Reeds

The amplitude and number of partials present in the spectra produced using the three reeds varied in this study. Both even and odd partials were present in all the samples. In some samples, the even partials have greater amplitudes than the odd partials such as G4 (349.23hh) at 80db in Table 5. F3 (155.56hz) at 84db generally produced stronger odd partials at the lower frequencies than either G4 or F5 (622.25hz). F5 tended to produce stronger odd partials beginning with the 7th partial for tones of high intensity.

A review of Tables 1 through 18 reveals that the amplitude and number of partials present in a spectrum varied between trials of the same frequency, intensity, and reed. Some amplitudes are duplicated while others are not for the same partial of a frequency. There are several samples of missing upper partials between samples of the same frequency and intensity. Table 8 shows one sample with a missing fundamental, but the presence of an additional partial not found in the other trials. An extreme example of missing partials and amplitude fluctations for F3 at 70db can be seen in Tables 20 and 28.

The data in Tables 1 through 37 show that the strongest partial was not always the fundamental. The exceptions were the spectra for G4 (349.23hz) which showed the fundamental to be strongest at both high and low intensities with all reeds. The fundamental was also strongest for the pitch F3 (155.56hz) with the hard reed. The spectrum for F5 (622.25hz) at 78db, produced with a soft reed, showed no measurable trace of the fundamental. The measured amplitude of the fundamental, a mean voltage of less than .1200, seems very low for F5 (622.25hz) at 78db produced with medium and hard reeds.

Fifty percent of the spectra show the 2nd partial as the strongest. These spectra represent the pitches F3 (155.56hz) at 84db with all reeds, F3 at 70db with soft and medium reeds, F5 (622.25hz) at 78db with all reeds, and F5 at 94db with a medium reed.

In Tables 16 and 18, the spectra data for the pitch F5 (622.25hz) at 94db with soft and hard reeds show the 7th partial to be the strongest. Tables 35 and 37 show the 7th partial as 549 percent of the fundamental for the soft reed, and 498 percent of the fundamental for the hard reed. The data in Table 36 show that the 7th partial was 427 percent of the fundamental for the medium strength reed. However, this was 169 percentage points less than the 2nd partial, which was 595 percent of the fundamental.

The soft reed generally produced more partials in a spectrum as shown in Table A. As reed stiffness increased, the number of partials in a spectrum gradually decreased. The data used to determine amplitude strength are based on percentages of the fundamental. Therefore, the first partial is not included in these data. The partials produced by soft and medium strength reeds generally had stronger amplitudes than partials produced from the hard reed.

With an increase of intensity, partials within a tone consistently increased. The number of partials within a loud tone increased with frequency. With soft tones, the increase of partials did not always follow and increase in frequency. In Tables 4 through 9,the pitch F5 (622.25hz) produced slightly fewer partials than the pitch G4 (349.23hz) with all reeds at low intensities. Slightly different intensity levels may have contributed to this effect.

Judges' Ratings of Tones

The 18 tones rated by the 16 judges are listed in rank order in Table B. The highest ranked tone was F3 (155.25hz) produced with the soft reed at 84db. The same pitch and loudness produced with the medium stiff reed were rated a very close second. The pitch F3 at 70db, produced with the hard reed, received the lowest rating. However, when the tones are grouped by pitch and intensity as in

Table A: A comparative analysis of the reeds

Frequency	155.56 Hz (F3)		349.23 Hz (G4)		622.25 Hz (F5)	
Intensity	70db	84db	80db	90db	78db	94db
Reed with Largest Number of Partials	soft	soft	soft medium (equal)	soft	medium	soft
Reed with Least Number of Partials	hard	hard	hard	hard	hard	hard
Strongest Total Amplitude of all Partials Present*	medium	soft	soft	medium	soft	hard
Weakest Total Amplitude of all Partials Present*	hard	hard	hard	soft	hard	medium

*Fundamental not included in the total.

Table B: Rank order of judges' ratings

Rank-	Sample No.-	Rating-	Pitch-	Dynamic Level-	Reed Stiffness
1	2	1.76	F3	loud	soft
2	8	1.98	F3	loud	medium
3	16	2.05	G4	loud	hard
4	15	2.18	G4	soft	hard
5	3	2.35	G4	soft	soft
6	14	2.40	F3	loud	hard
7	7	2.69	F3	soft	medium
8	9	2.74	G4	soft	medium
9	17	2.89	F5	soft	hard
10	5	3.00	F5	soft	soft
11	11	3.00	F5	soft	medium
12	12	3.01	F5	loud	medium
13	1	3.02	F3	soft	soft
14	18	3.10	F5	loud	hard
15	6	3.14	F5	soft	soft
16	10	3.20	G4	loud	medium
17	4	3.29	G4	loud	soft
18	13	3.79	F3	soft	hard

A rating of "1" is superior to a rating of "5".

	Frequency		
	155.56 Hz (F3)	349.23 Hz (G4)	622.25 Hz (F5)
Reed Rated Highest for Loud tones	soft	hard	medium
Reed Rated Highest for Soft tones	medium	hard	hard

Figure 10. Judges' tonal preference by pitch

Figure 10, the hard reed produced 50 percent of those tones as compared to 33 percent with the medium stiff reed, and to 17 percent of the tones produced with the soft reed.

Table 38 reveals that the six higher ranking tones were generally rated high in terms of being free, full, solid, and resonant. The tonal descriptors of mellow, focused, and clear had less of an influence on the ratings. This can be seen in the data for samples 2, 8, and 13 of Table 38.

A composite mean score for all samples produced with the same reed provided little information towards a clear preference for tones produced with a specific reed. The soft reed has the highest single tone rating and a composite mean rating of 2.76. The hard reed has a composite mean rating of 2.734 and received the lowest single tone rating of 3.79. The composite mean rating for the medium reed is 2.77.

Figure 10 reveals that F3 (155.56hz) produced with a soft reed at 84db was rated superior, and F3 produced with a hard reed at 70db was rated inferior to the other tones. F5 (622.25hz) at 78 db produced with the hard reed was rated 9th overall, and the best for that frequency. Evidence cited earlier indicated that the softer reed and higher intensity should produce more partials with greater amplitudes. A review of the data in Tables 3,10,21, and 29 reveals a difference in the ratio of partials present. The hard reed produced the only spectrum samples of F3 in which the fundamental was the strongest. The 3rd partial was 54 percent of the fundamental in only one trial sample, and the mean ratio was 34 percent. In the spectra for F3 produced with the soft reed, the 2nd partial is the most prominent with 154 percent of the fundamental. The 3rd partial represents an average of 112 percent of the fundamental. Table 28, Trial 2, shows that F5 had an unusually strong 2nd partial, and a lesser but strong 3rd partial. The only other partial present was a weak fundamental. This may represent a difference in formant and the number of partials that are desirable for a given frequency and timbre.

CHAPTER V

SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

Summary

A survey of the literature related to the acoustical phenomenon of the clarinet yielded little information relative to the effects of varying the stiffness of a clarinet reed. Much that has been written on the subject in pedagogical literature has been based on subjective observations and traditional theories. Searching the literature did not produce studies that analyzed clarinet spectra produced by reeds of various stiffnesses.

The basis of this investigation was to examine, through a systematic method, the tonal spectra of three reeds cut by a standard manufacturer into three levels of stiffness. The study involved examining the influence of reed strength, intensity level, and frequency level on the harmonic structure of tones produced on a Bb clarinet.

One professional clarinetist performed a sustained tone on three frequencies representing the chalumeau, throat, and clarion registers, on each of the three reeds, at two intensity levels corresponding to the piano and forte dynamic levels. Each tone sample was performed three times for each frequency, intensity, and reed. The tones were recorded in an acoustically treated room with a sound level meter to control the intensity level and a digital tuner to tune the clarinet. Three reeds representative of soft, medium, and hard stiffnesses and one Bb clarinet were used to produce the tonal samples. A high-quality reel-to-reel tape recorder was used to record the samples.

The recorded tones were channeled into a spectrum analyzer which produced a graphic representation of the radiated waveform. A printer plotted the spectrum for each sample for visual analysis.

The plotted tonal spectra were reviewed to investigate the number and strength of partials produced under the conditions of reed strength, intensity, and pitch. The data from each spectrum were quantified and listed in tables for visual analysis.

Eighteen of the recorded samples, representing each condition of intensity, pitch, and reed stiffness, were selected for an aural rating by a group of 16 judges. To account for order effects, three variations of the tape were made for three groups of judges. These recorded tones were presented using identical headphones and a checklist to record the ratings.

Conclusions

The following conclusions and observations are based on a visual examination of the data that graphically represent the various waveforms of a Bb clarinet.

The amplitude and number of partials present in the spectra of clarinet tone samples varied. Irrespective of the number present, all samples produced both even and odd partials. The spectra did not produce an absence of even partials as would be expected acoustically from a pipe stopped at one end. The even partials occurred in amplitudes equal to and greater than the odd partials. Data tables in a study of clarinet spectra by Lawson (1975) also show an equal number of even and odd harmonics present in his samples. Backus (1977, pp 240 -243) explained that the even partials become prominent when their frequencies lie near or coincide with the resonance frequencies of a clarinet.

The amplitude and number of partials present in a spectrum varied among trials of the same frequency, intensity, reed, and performer. These differences are represented in spectra samples as missing partials, partials found in only one sample of a frequency, and unusual amplitude measurements. This seems to be an effect of the performer, and the inability of humans to repeat identical responses mechanically. In addition, the points at which the spectrum sweeps were taken varied in terms of time between initial transient and decay.

The partial with the greatest amplitude in a spectrum varied with the frequency of the fundamental. The fundamental was strongest at both high and low intensities with all reeds in the spectra representing G4 (349.23hz), and for the spectra representing F3 (155.56hz) with the hard reed. No fundamental was detected in the spectrum for F5 (622.25hz) at 78db that was produced with the soft reed. In the spectra representing the pitches F3 at 84db, and F5 at 78db, the 2nd partial had the greatest amplitude with all of the reeds. F3 at 70db with soft and medium reeds, and F5 at 94db with the medium stiff reed also had the 2nd partial as the strongest in the spectrum. With the soft and hard reeds, the 7th partial was found to have the greatest amplitude in the spectra for the pitch F5 at 94db. In relation to the formant theory, these data suggest that the clarinet may have a different formant for each register.

In general, the soft reed produced more partials in a spectrum. Conversely, the hard reed produced fewer partials in a spectrum than medium or soft reeds. As intensity and frequency increased, the number of partials within a spectrum consistently increased. However, the number of partials did not necessarly increase with an increase of frequency with soft tones. The higher fundamental frequency in this study, F5 (622.25hz) produces a weak fundamental in general which may be totally absent at low intensities. F5 produced with the hard reed was rated 9th overall by the judges and the best for that pitch. Of interest is that only three partials were present, a weak fundamental, a powerful 2nd partial, and a strong 3rd partial. This supports Backus' theory that partials above a certain number may be undesirable in a musical tone.

The tonal descriptors used more frequently by the judges to rate the tone samples were free, full, solid, and resonant. The terms clear, mellow, and focused were seldom used to rate a tone as superior or inferior.

The performance of F3 (155.25hz) at 84db with the soft reed was rated as the superior tone in the sample. The tone rated as most inferior was F3 at 70db performed with the hard reed. However, a composite mean, computed for all tones performed with the same reed, showed the reeds to be almost equally rated overall. When viewed according to individual pitches, the hard reed was rated higher more times than the medium or soft reed. The differences among these ratings are too small to develop specific conclusions about timbre preferences and the reeds that produced the tones. In general, the timbre preferences of clarinetists remain subjective and personal.

Recommendations for Further Research

The findings in this study suggest the following recommendations for further research:

1. A subject of concern in a study such as this is the number of human subjects who participate in the treatment process for the purpose of generalization. The

range of variation produced in this study with one performer suggests that a more controlled approach may be warranted. The use of a mechanical embouchure, to eliminate the influence of the performer on the harmonic structure of tones, may produce interesting results.

2. The method used to collect data on clarinet timbre preferences involved presenting sustained tones to be rated. Performing a musical phrase with various reeds within a selected range of pitches and dynamics may elicit more discriminating responses.

3. The reeds in the present study were based on average ratings of stiffness. A study of reeds with a wider range of elasticity may provide more dramatic results.

4. The number and amplitude of even-numbered partials in a clarinet tone spectrum has yet to be fully explained. Further research in this area is strongly needed.

Implications of the Study

The variations in spectra produced in this study under controlled conditions demonstrates the vast amount of changes that occur in a musical performance. These differences possibly occur in a manner so subtle that the listener is totally unaware. The performer may view these changes as expressive devices used to enhance a performance. The variations produced by the same performer from trial to trial indicated that a different harmonic structure is created each time a tone is played on a clarinet.

In our pluralistic society today, tradition has given way to the acceptance of a variety of sounds as musical. Clarinetists are required to adjust their tone quality to blend with other instruments and to play contrasting styles. The human element in performance is critical in aesthetic expression. Although the present investigation required controlled samples to isolate effects, other research is being conducted to produce these human effects in synthesized sounds.

The information produced by this study must be viewed simply as additional data to be considered when describing the acoustical phenomenon of the clarinet.

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APPENDIX A

Equipment Used in Study

Commodore 64 Computer

M T R Computer Monitor

Commodore 1541 Disk Drive

Star SG-10 Printer

Pioneer 1020L Reel to Reel Tape Recorder

Audio-Technicia Model ATM-63 Microphone

TDK Audua Recording Tape 1.5 mil

Realistic Sound Level Meter #33-2050

Boss B-12 Digital Tuner

Computer Continum Analog Interface Board,

8 channels A/D and 8 channels D/A

Commodore 64 Scope/FFT program

Commodore 64 CPM card

Buffet R-13 Bb Clarinet

Harrison Hertz Ligature(gold)

Anthony Spano Mouthpiece #S2

Technics Model EAH-810 Headphones

APPENDIX B

Table 1

Mean strength of partials for each performer, at one intensity, one reed strength, and one frequency.

Pitch: F 155.56hz Intensity: 70db Reed Stiffness: soft

	Trial Number			
Partial No.	1	2	3	*Mean
1	.1822	.2083	.2864	.2256
2	.3385	.2604	.3645	.3211
3	.1041	.1041	.1041	.1041
4	.1041	- 0 -	- 0 -	.0347

n=3

*Mean strength for each partial.

Table 2

Mean strength of partials for each performer, at one intensity, one reed strength, and one frequency.

Pitch: F 155.56hz Intensity: 70db Reed Stiffness: medium

	Trial Number			
Partial No.	1	2	3	*Mean
1	.1302	.3385	.3645	.2777
2	.5208	.4427	.3385	.4340
3	- 0 -	.1822	.1302	.1041
4	- 0 -	.1041	- 0 -	.0347

n=3

*Mean strength for each partial.

Table 3

Mean strength of partials for each performer, at one intensity, one reed strength, and one frequency.

Pitch: F 155.56hz Intensity: 70db Reed Stiffness: Hard

	Trial Number			
Partial No.	1	2	3	*Mean
1	.4427	.4947	.3385	.4253
2	.2864	.4427	.3645	.3645
3	.1302	.1041	.1822	.1388
4	- 0 -	- 0 -	- 0 -	- 0 -

n=3

*Mean strength for each partial.

Table 4

Mean strength of partials for each performer, at one intensity, one reed strength, and one frequency.

Pitch: G' 349.23hz Intensity: 80db Reed Stiffness: soft

	Trial Number			
Partial No.	1	2	3	*Mean
1	1.223	1.119	1.145	1.1623
2	.2864	.4166	.3385	.3472
3	.3385	.2083	.4947	.3472
4	.4166	.4166	.5208	.4513
5	.6510	.4947	.3385	.4947
6	.2864	.3385	.2604	.2951
7	.1822	.2864	.1041	.1909

n=3

*Mean strength for each partial.

Table 5

Mean strength of partials for each performer, at one intensity, one reed strength, and one frequency.

Pitch: G' 349.23hz Intensity: 80db Reed Stiffness: medium

	Trial Number			
Partial No.	1	2	3	*Mean
1	1.432	1.380	1.354	1.3886
2	.4427	.5729	.5729	.5295
3	.2864	.2604	.3645	.3037
4	.4427	.4427	.5208	.4687
5	.4427	.4166	.5208	.4600
6	.2083	.2604	.1302	.1996
7	.1302	.1302	.1822	.1475

n=3

*Mean strength for each partial.

Table 6

Mean strength of partials for each performer, at one intensity, one reed strength, and one frequency.

Pitch: G' 349.23hz Intensity: 80db Reed Stiffness: medium

	Trial Number			
Partial No.	1	2	3	*Mean
1	1.432	1.848	1.614	1.6313
2	.4166	.5729	.5729	.5208
3	.3645	.4429	.4947	.4339
4	.3385	.6770	.5208	.5121
5	.3645	.4947	.3645	.4079
6	.1302	.1302	.1302	.1302
7	- 0 -	.1822	- 0 -	.0607
8	.1041	- 0 -	- 0 -	.0347

n=3

*Mean strength for each partial.

Table 7

Mean strength of partials for each performer, at one intensity, one reed strength, and one frequency.

Pitch: F'' 622.25hz Intensity: 78db Reed Stiffness: soft

	Trial Number			
Partial No.	1	2	3	*Mean
1	- 0 -	- 0 -	- 0 -	- 0 -
2	.5989	.5989	.5208	.5728
3	.2083	.1302	.1041	.1475
4	.3385	.2864	.3645	.3298
5	.1041	.1302	.1822	.1388
6	.1822	.1302	.2083	.1735
7	.1302	.1302	.2083	.1562
8	- 0 -	.1041	- 0 -	.0347

n=3

*Mean strength for each partial.

Table 8

Mean strength of partials for each performer, at one intensity, one reed strength, and one frequency.

Pitch: F'' 622.25hz Intensity: 78db Reed Stiffness: medium

	Trial Number			
Partial No.	1	2	3	*Mean
1	.1041	.1302	.1041	.1128
2	.6770	.6770	.6770	.6770
3	.1822	.1041	.1302	.1388
4	.1041	.1302	.1302	.1215
5	.1822	.1041	.1041	.1301
6	.1041	- 0 -	- 0 -	.0347
7	- 0 -	- 0 -	- 0 -	- 0 -
8	- 0 -	- 0 -	- 0 -	- 0 -

n=3

*Mean strength for each partial.

Table 9

Mean strength of partials for each performer, at one intensity, one reed strength, and one frequency.

Pitch: F'' 622.25hz Intensity: 78db Reed Stiffness: hard

	Trial Number			
Partial No.	1	2	3	*Mean
1	.1822	.0520	.1041	.1127
2	.7289	.5208	.6770	.6422
3	.1302	.1302	.1041	.1215
4	- 0 -	- 0 -	.1041	.0347
5	.1822	- 0 -	.1302	.1041
6	- 0 -	- 0 -	.1041	.0347
7	- 0 -	- 0 -	- 0 -	- 0 -
8	- 0 -	- 0 -	- 0 -	- 0 -

n=3

*Mean strength for each partial.

Table 10

Mean strength of partials for each performer, at one intensity, one reed strength, and one frequency.

Pitch: F 155.56hz Intensity: 84db Reed Stiffness: soft

	Trial Number			
Partial No.	1	2	3	*Mean
1	.9635	.8333	.8072	.8680
2	1.5100	1.0670	1.4580	1.345
3	.9895	.9635	.9635	.9721
4	.9114	.2864	.6510	.6162
5	.4427	.2864	.4427	.3906
6	.1302	.2864	.1041	.1735
7	.1041	.1302	.1041	.1128
8	.1041	.1041	.1041	.1041
9	.1041	.1041	- 0 -	.0694
10	.1041	- 0 -	- 0 -	.0347
12	- 0 -	.1041	- 0 -	.0347

n=3

*Mean strength for each partial.

Table 11

Mean strength of partials for each performer, at one intensity, one reed strength, and one frequency.

Pitch: F 155.56hz Intensity: 84db Reed Stiffness: medium

	Trial Number			
Partial No.	1	2	3	*Mean
1	1.2760	1.1970	1.5880	1.3536
2	1.4320	1.6140	1.8480	1.6313
3	.9635	1.0150	1.2230	1.0671
4	.4947	.5208	.5729	.5294
5	.2083	.2864	.2864	.2603
6	.2864	.3385	.2083	.2777
7	.1302	.1302	.2083	.1562
8	- 0 -	- 0 -	.1041	.0347
9	- 0 -	.1041	.1041	.0694

n=3

*Mean strength for each partial.

Table 12

Mean strength of partials for each performer, at one intensity, one reed strength, and one frequency.

Pitch: F 155.56hz Intensity: 84db Reed Stiffness: hard

	Trial Number			
Partial No.	1	2	3	*Mean
1	1.5100	.9895	1.4320	1.3105
2	1.6660	1.7770	1.5100	1.6486
3	1.2765	.5729	.8072	.8853
4	.5208	.4166	.2604	.3992
5	- 0 -	.1302	.3645	.1649
6	.1041	.2083	.2083	.1735
7	- 0 -	.1302	.2604	.1302
8	- 0 -	.1041	.1041	.0694
9	- 0 -	- 0 -	.1302	.0434

n=3

*Mean strength for each partial.

Table 13

Mean strength of partials for each performer, at one intensity, one reed strength, and one frequency.

Pitch: G 349.23hz Intensity: 90db Reed Stiffness: soft

	Trial Number			
Partial No.	1	2	3	*Mean
1	2.2390	2.3690	2.2390	2.2820
2	.7552	.8072	.6510	.7378
3	.4947	.7552	.5468	.5989
4	.8072	.8072	.8854	.8332
5	1.1450	1.2760	1.3020	1.2410
6	.9895	1.1190	.9895	1.0326
7	.4166	.7522	.5989	.5902
8	.6510	.7552	.8072	.7378
9	.5729	.5208	.7291	.6076
10	.3385	.3645	.4947	.3992
11	.3385	.2083	.5208	.3558
12	.5729	.6510	.4166	.5468
13	.4166	.4427	.2864	.3819
14	.1822	.1822	.2604	.2082
15	- 0 -	.1822	.1041	.0954
16	.2604	.2083	.3385	.2690
17	.1302	.1302	.2604	.1736
18	.1041	- 0 -	.1302	.0781
19	.1041	- 0 -	.1041	.0694
22	- 0 -	- 0 -	.1041	.0347
23	- 0 -	- 0 -	.1041	.0347
24	- 0 -	- 0 -	.1041	.0347
25	.1041	- 0 -	- 0 -	.0347
26	.1041	.1302	- 0 -	.0781
27	- 0 -	- 0 -	.1302	.0434

n=3

*Mean strength for each partial.

Table 14

Mean strength of partials for each performer, at one intensity, one reed strength, and one frequency.

Pitch: G 349.23hz Intensity: 90db Reed Stiffness: medium

	Trial Number			
Partial No.	1	2	3	*Mean
1	2.6820	2.4730	2.6820	2.6123
2	1.1190	.9114	.8072	.9458
3	.4947	.8072	.6770	.6596
4	1.0670	.8072	1.2230	1.0324
5	.7552	.9635	1.5100	1.0762
6	1.1190	.9114	1.3540	1.1281
7	.5989	.6510	.9635	.7378
8	.6770	.5989	.4166	.5641
9	.4166	.4166	.4947	.4426
10	.3385	.1041	.2083	.2169
11	.3385	.1822	.2864	.2690
12	.1302	.1302	- 0 -	.0868
13	.2864	.1041	.1302	.1735
14	.1302	.1041	.1041	.1128
15	- 0 -	.1041	- 0 -	.0347
16	.1041	- 0 -	- 0 -	.0347

n=3
*Mean strength for each partial.

Table 15

Mean strength of partials for each performer, at one intensity, one reed strength, and one frequency.

Pitch: G 349.23hz Intensity: 90db Reed Stiffness: hard

	Trial Number			
Partial No.	1	2	3	*Mean
1	2.9940	2.8380	2.9160	2.9160
2	1.1970	1.1190	.7291	1.0150
3	1.1450	1.0670	1.3800	1.1973
4	2.3170	2.8950	1.9270	2.3776
5	.8333	.9114	.3645	.7031
6	.9895	1.1450	.9635	1.0326
7	.8333	.8072	.8854	.8419
8	.4166	.2864	.3645	.3558
9	- 0 -	.1822	.1822	.1214
10	.3645	.3645	.2604	.3298
11	.1822	.2864	.2083	.2256
12	.1302	.1302	- 0 -	.0868
13	- 0 -	- 0 -	.1041	.0347
14	- 0 -	.1302	- 0 -	.0434
15	- 0 -	.1041	- 0 -	.0347
16	.1041	.1041	- 0 -	.0694
17	.1041	.1041	- 0 -	.0694

n=3
*Mean strength for each partial.

Table 16

Mean voltage of partials for one frequency, at one intensity, with one reed strength, and one performer.

Pitch: F5 622.25hz Intensity: 94db Reed Stiffness: soft

	Trial Number			
Partial No.	1	2	3	*Mean
1	.6770	.4166	.4427	.5121
2	3.0980	1.9010	1.5100	2.1696
3	.6510	.6510	.5989	.6376
4	1.1450	.8072	.7552	.9025
5	.9895	1.0670	.9635	1.0066
6	2.2910	2.8380	2.3950	2.5080
7	2.6300	3.1770	2.6300	2.8123
8	.8854	1.0410	.9114	.9459
9	1.4580	1.6140	1.2760	1.4493
10	.5729	.5989	.4947	.5555
11	1.0150	.7291	.2645	.7029
12	.2604	.3645	.2083	.2777
13	.4427	.8333	.8072	.6944
14	.1822	.3385	.2083	.2430
15	.2864	.3645	.2083	.2864
16	.2604	.2604	.2083	.2430
17	.2864	.4947	.3645	.3818
18	.2864	.1822	.2864	.2517
19	.1822	.1041	.1302	.1388
20	.1041	.1041	.1302	.1128
21	.1302	.1041	- 0 -	.0781
22	.2864	.2604	.1822	.2430
23	.1041	- 0 -	.1041	.0694
24	.3385	.2864	.1041	.2430
26	.2083	.1041	.1041	.1388
27	- 0 -	- 0 -	.1041	.0347
28	.1041	- 0 -	.1041	.0694
29	- 0 -	.1041	- 0 -	.0347
31	.1041	- 0 -	- 0 -	.0347
35	- 0 -	.1041	- 0 -	.0347

n=3 Voltage Range 0 - 5

*Mean strength for each partial.

Table 17

Mean voltage of partials for one frequency, at one intensity, with one reed strength, and one performer.

Pitch: F5 622.25hz Intensity: 94db Reed Stiffness: medium

	Trial Number			
Partial No.	1	2	3	*Mean
1	.4427	.6510	.7552	.6163
2	2.8640	3.8020	4.3480	3.6713
3	.9895	1.1450	1.1970	1.1105
4	1.0670	1.7440	1.3800	1.3970
5	1.0670	.6770	.8333	.8591
6	2.2390	2.1350	1.5880	1.9873
7	2.7860	2.9420	2.1610	2.6296
8	.8854	.8333	.6770	.7986
9	.9895	1.4320	.9895	1.1370
10	.4427	.6510	.4166	.5034
11	.4947	.4427	.5729	.5034
12	.2083	.4427	.2604	.3038
13	.3385	.4947	.2604	.3645
14	.2604	.3385	.2604	.2864
15	.4427	.3385	.2083	.3298
16	.1302	.2083	.1822	.1736
17	.1302	.2604	.1302	.1736
18	.1041	.2083	.1302	.1475
19	- 0 -	.1302	.1041	.0781
20	- 0 -	.1822	.1302	.1041
21	.1041	.1302	.1041	.1128
22	.1041	.1822	.1041	.1301
23	- 0 -	.1302	- 0 -	.0434
25	- 0 -	.1302	.1302	.0868
26	- 0 -	.1822	.1302	.1041
29	- 0 -	.1302	- 0 -	.0434

n=3 Voltage Range 0 - 5

*Mean strength for each partial.

Table 18

Mean voltage of partials for one frequency, at one intensity, with one reed strength, and one performer.

Pitch: F5 622.25hz   Intensity: 94db   Reed Stiffness: hard

	Trial Number			
Partial No.	1	2	3	*Mean
1	.4166	.5208	.5729	.5034
2	1.6920	1.8220	2.0830	1.8656
3	.6770	.8854	.8854	.8159
4	2.0050	2.5000	2.0050	2.1700
5	1.7440	1.5880	.8333	1.3884
6	2.0050	1.4580	1.7700	1.7443
7	2.3690	2.1610	2.9940	2.5080
8	.6510	.6510	.9635	.7551
9	.8072	.5989	1.1190	.8417
10	.2864	.3645	.4947	.3819
11	.9635	1.1190	1.1450	1.0758
12	.1822	.2604	.2864	.2430
13	.2864	.3645	.3645	.3384
14	.1822	2083	.2604	.2430
15	.2604	.2864	.2083	.2509
16	.1041	.2083	.2864	.1996
17	.1822	.1822	.2083	.1909
18	.2604	.1302	.1302	.1736
19	.1041	.1041	- 0 -	.0694
20	.2083	.1302	.1302	.1562
21	.1041	- 0 -	.1302	.0781
22	.1302	- 0 -	.1302	.0868
23	- 0 -	- 0 -	.1041	.0347
24	.1041	.1041	- 0 -	.0694
25	- 0 -	.1302	.1302	.0868
29	- 0 -	- 0 -	.1041	.0347

n=3   Voltage Range 0 - 5

*Mean strength for each partial.

Table 19

Percentage of fundamental found in each partial for one frequency, at one intensity, with one reed strength, and one performer.

Pitch: F3 155.56hz Intensity: 70db Reed Stiffness: soft

	Trial Number			
Partial No.	1	2	3	*Mean
1				
2	185.78	125.00	127.27	142.33
3	57.14	49.98	36.35	46.14
4	57.14	0.00	0.00	15.38

*Mean percentage for each partial.

Table 20

Percentage of fundamental found in each partial for one frequency, at one intensity, with one reed strength, and one performer.

Pitch: F3 155.56hz Intensity: 70db Reed Stiffness: medium

	Trial Number			
Partial No.	1	2	3	*Mean
1				
2	400.00	130.78	92.87	156.28
3	0.00	53.83	35.72	37.49
4	0.00	30.75	0.00	12.50

*Mean percentage for each partial.

Table 21

Percentage of fundamental found in each partial for one frequency, at one intensity, with one reed strength, and one performer.

Pitch: F3 155.56hz Intensity: 70db Reed Stiffness: hard

	Trial Number			
Partial No.	1	2	3	*Mean
1				
2	64.69	89.49	107.68	85.70
3	29.41	21.04	53.83	32.65

*Mean percentage for each partial.

Table 22

Percentage of fundamental found in each partial for one frequency, at one intensity, with one reed strength, and one performer.

Pitch: G4 349.23hz Intensity: 80db Reed Stiffness: soft

	Trial Number			
Partial No.	1	2	3	*Mean
1				
2	23.42	37.23	29.56	21.39
3	27.68	18.61	43.21	21.39
4	34.06	37.23	45.48	38.83
5	53.23	44.21	29.56	42.56
6	23.42	30.25	22.74	25.40
7	14.90	25.59	9.09	16.42

*Mean percentage for each partial.

Table 23

Percentage of fundamental found in each partial for one frequency, at one intensity, with one reed strength, and one performer.

Pitch: G4 349.23hz Intensity: 80db Reed Stiffness: medium

	Trial Number			
Partial No.	1	2	3	*Mean
1				
2	30.91	41.51	42.31	38.13
3	20.00	18.87	26.92	21.87
4	30.91	32.08	38.46	33.75
5	30.91	30.19	38.46	33.13
6	14.55	18.87	9.62	14.37
7	9.09	9.43	13.46	10.62

*Mean percentage for each partial.

Table 24

Percentage of fundamental found in each partial for one frequency, at one intensity, with one reed strength, and one performer.

Pitch: G4 349.23hz Intensity: 80db Reed Stiffness: hard

	Trial Number			
Partial No.	1	2	3	*Mean
1				
2	29.09	31.00	35.50	31.93
3	25.45	23.97	30.65	26.60
4	23.64	36.63	32.27	31.39
5	25.45	26.77	22.58	25.00
6	9.09	7.05	8.07	7.98
7	0.00	9.86	0.00	3.72
8	7.27	0.00	0.00	2.13

*Mean percentage for each partial.

Table No. 25

Percentage of fundamental found in each partial for one frequency, at one intensity, with one reed strength, and one performer.

Pitch: F5 622.25hz Intensity: 78db Reed Stiffness: soft

	Trial Number			
Partial No.	1	2	3	*Mean
1				
2	.	.	.	.
3	.	.	.	.
4	.	.	.	.
5	.	.	.	.
6	.	.	.	.
7	.	.	.	.
8	.	.	.	.

*Mean percentage for each partial.
** Fundamental absent in these samples.

Table 26

Percentage of fundamental found in each partial for one frequency, at one intensity, with one reed strength, and one performer.

Pitch: F5 622.25hz Intensity: 78db Reed Stiffness: medium

	Trial Number			
Partial No.	1	2	3	*Mean
1				
2	650.34	519.97	650.34	600.18
3	175.02	79.95	125.07	123.05
4	100.00	100.00	125.07	107.71
5	175.02	79.95	100.00	115.34
6	100.00	0.00	0.00	30.76

*Mean percentage for each partial.

Table 27

Percentage of fundamental found in each partial for one frequency, at one intensity, with one reed strength, and one performer.

Pitch: F5 622.25hz Intensity: 78db Reed Stiffness: hard

	Trial Number			
Partial No.	1	2	3	*Mean
1				
2	400.05	1001.54	650.34	569.83
3	71.46	250.38	100.00	107.81
4	0.00	0.00	100.00	30.79
5	100.00	0.00	125.07	92.37
6	0.00	0.00	100.00	30.79

*Mean percentage for each partial.

Table 28

Percentage of fundamental found in each partial for one frequency, at one intensity, with one reed strength, and one performer.

Pitch: F3 155.56hz Intensity: 84db Reed Stiffness: soft

	Trial Number			
Partial No.	1	2	3	*Mean
1				
2	156.72	128.05	180.62	154.95
3	102.70	115.62	119.36	111.99
4	94.59	34.37	80.65	70.99
5	45.95	34.37	54.84	45.00
6	13.51	34.37	12.90	18.99
7	10.80	15.62	12.90	13.00
8	10.80	12.49	12.90	11.99
9	10.80	12.49	0.00	8.00
10	10.80	0.00	0.00	4.00
12	0.00	12.49	0.00	4.00

*Mean percentage for each partial.

Table 29

Percentage of fundamental found in each partial for one frequency, at one intensity, with one reed strength, and one performer.

Pitch: F3 155.56hz Intensity: 84db Reed Stiffness: medium

	Trial Number			
Partial No.	1	2	3	*Mean
1				
2	112.23	134.84	116.37	120.52
3	75.51	84.80	77.02	78.83
4	38.77	43.51	36.08	39.11
5	16.32	23.93	18.04	19.23
6	22.45	28.28	13.12	20.52
7	10.20	10.88	13.12	11.54
8	0.00	0.00	6.56	2.56
9	0.00	8.70	6.56	5.13

*Mean percentage for each partial.

Table 30

Percentage of fundamental found in each partial for one frequency, at one intensity, with one reed strength, and one performer.

Pitch: F3 155.56hz Intensity: 84db Reed Stiffness: hard

	Trial Number			
Partial No.	1	2	3	*Mean
1				
2	110.33	179.59	105.45	125.80
3	84.54	57.90	56.37	67.55
4	34.49	42.10	18.18	30.46
5	0.00	13.16	25.45	12.58
6	6.89	21.05	14.55	13.24
7	0.00	13.16	18.18	9.94
8	0.00	10.52	7.27	5.30
9	0.00	0.00	9.09	3.31

*Mean percentage for each partial.

Table 31

Percentage of fundamental found in each partial for one frequency, at one intensity, with one reed strength, and one performer.

Pitch: G4 349.23hz Intensity: 90db Reed Stiffness: soft

	Trial Number			
Partial No.	1	2	3	*Mean
1				
2	33.73	34.07	29.08	32.33
3	22.09	31.88	24.42	26.24
4	36.05	53.86	58.15	54.38
6	44.19	47.24	44.19	45.25
7	18.61	31.88	26.75	25.86
8	29.08	31.88	26.75	25.86
9	25.59	21.98	32.56	26.63
10	15.12	15.39	22.09	17.49
11	15.12	8.79	23.26	15.59
12	25.29	27.48	18.61	23.96
13	18.61	18.69	12.79	16.74
14	8.14	7.69	11.63	9.12
15	0.00	7.69	4.65	4.18
16	11.63	8.79	15.12	11.79
17	5.82	5.50	11.63	7.61
18	4.65	0.00	5.82	3.42
19	4.65	0.00	4.65	3.04
22	0.00	0.00	4.65	1.52
23	0.00	0.00	4.65	1.52
24	0.00	0.00	4.65	1.52
25	4.65	0.00	0.00	1.52
26	4.65	5.50	0.00	3.42
27	0.00	0.00	5.82	1.90

*Mean percentage for each partial.

Table 32

Percentage of fundamental found in each partial for one frequency, at one intensity, with one reed strength, and one performer.

Pitch: G4 349.23hz Intensity: 90db Reed Stiffness: medium

	Trial Number			
Partial No.	1	2	3	*Mean
1				
2	41.72	36.85	30.10	36.21
3	18.45	32.64	25.24	25.25
4	39.78	32.64	45.60	39.52
5	28.16	38.96	56.30	41.20
6	41.72	36.85	50.48	43.18
7	22.33	26.32	35.92	28.24
8	25.24	24.22	15.53	21.59
9	15.53	16.85	18.45	16.94
10	12.62	4.21	7.77	8.30
11	12.62	7.37	10.68	10.30
12	4.85	5.26	0.00	3.32
13	10.68	4.21	4.85	6.64
14	4.85	4.21	3.88	4.32
15	0.00	4.21	0.00	1.33
16	3.88	0.00	0.00	1.33

*Mean percentage for each partial.

Table 33

Percentage of fundamental found in each partial for one frequency, at one intensity, with one reed strength, and one performer.

Pitch: G4 349.23hz Intensity: 90db Reed Stiffness: hard

	Trial Number			
Partial No.	1	2	3	*Mean
1				
2	39.98	39.43	25.00	34.81
3	38.24	37.60	47.33	41.06
4	77.39	102.01	66.08	81.54
5	27.83	32.11	12.50	24.11
6	33.05	40.35	33.04	35.41
7	27.83	28.44	30.36	28.84
8	13.91	10.09	12.50	12.20
9	0.00	6.42	6.25	4.16
10	12.17	12.84	8.93	11.31
11	6.09	10.09	7.14	7.74
12	4.35	4.59	0.00	2.98
13	0.00	0.00	3.57	1.19
14	0.00	4.59	0.00	1.49
15	0.00	3.67	0.00	1.19
16	3.48	3.67	0.00	2.38
17	3.48	3.67	0.00	2.38

*Mean percentage for each partial.

Table 34

Percentage of fundamental found in each partial for one frequency, at one intensity, with one reed strength, and one performer.

Pitch: F5 622.25hz Intensity: 94db Reed Stiffness: soft

	Trial Number			
Partial No.	1	2	3	*Mean
1				
2	457.61	456.31	341.09	423.67
3	96.16	156.27	135.28	124.51
4	169.13	193.76	170.59	176.24
5	146.16	256.12	217.64	196.56
6	338.40	681.23	541.00	489.25
7	388.48	762.60	594.08	549.17
8	130.78	249.88	205.87	184.71
9	215.36	387.42	288.23	283.01
10	84.62	143.76	111.75	108.47
11	149.93	175.01	59.75	137.26
12	38.46	87.49	47.05	54.23
13	65.39	200.02	182.34	135.60
14	26.91	81.25	47.05	47.45
15	42.30	87.49	47.05	55.93
16	38.46	62.51	47.05	47.45
17	42.30	118.75	82.34	74.56
18	42.30	43.73	64.69	49.15
19	26.91	24.99	29.41	27.10
20	15.38	24.99	29.41	22.03
21	19.23	24.99	0.00	15.25
22	42.30	62.51	41.16	47.45
23	15.38	0.00	23.51	13.55
24	50.00	68.75	23.51	47.45
26	30.77	24.99	23.51	27.10
27	0.00	0.00	23.51	6.78
28	15.38	0.00	23.51	13.55

*Mean percentage for each partial.

Table 35

Percentage of fundamental found in each partial for one frequency, at one intensity, with one reed strength, and one performer.

Pitch: F5 622.25hz Intensity: 94db Reed Stiffness: medium

	Trial Number			
Partial No.	1	2	3	*Mean
1				
2	646.94	584.02	575.74	595.70
3	223.51	175.88	158.50	180.19
4	241.02	267.90	182.73	226.68
5	241.02	103.99	110.34	139.40
6	505.76	327.96	210.26	322.46
7	629.32	451.92	286.15	426.68
8	200.00	128.00	89.65	129.58
9	223.51	219.97	131.02	184.49
10	100.00	100.00	55.16	81.68
11	111.75	68.00	75.86	81.68
12	47.05	68.00	34.48	49.29
13	76.46	75.99	34.48	59.14
14	58.82	52.00	34.48	46.47
15	100.00	52.00	27.58	53.51
16	29.41	32.00	24.13	28.17
17	29.41	40.00	17.24	28.17
18	23.51	32.00	17.24	23.93
19	0.00	20.00	13.70	12.69
20	0.00	27.99	17.24	16.89
21	23.51	20.00	13.70	18.30
22	23.51	27.99	13.70	21.11
23	0.00	20.00	0.00	7.04
25	0.00	20.00	17.24	14.08
26	0.00	27.99	17.24	16.89

*Mean percentage for each partial.

Table No. 36

Percentage of fundamental found in each partial for one frequency, at one intensity, with one reed strength, and one performer.

Pitch: F5 622.25hz Intensity: 94db Reed Stiffness: hard

	Trial Number			
Partial No.	1	2	3	*Mean
1				
2	406.14	349.85	363.59	370.60
3	162.51	170.01	154.55	162.08
4	481.28	480.03	349.97	431.07
5	418.63	304.92	145.45	275.80
6	481.28	279.95	308.95	346.50
7	568.65	414.94	522.60	498.21
8	156.27	125.00	168.18	150.00
9	193.76	115.00	195.32	167.20
10	68.75	70.00	86.35	75.86
11	231.28	214.86	199.86	213.71
12	43.75	50.00	50.00	48.27
13	68.75	70.00	63.62	67.22
14	43.73	40.00	45.45	48.27
15	62.51	55.00	36.36	49.84
16	24.99	40.00	50.00	39.65
17	43.73	35.00	36.36	37.92
18	62.51	25.00	22.73	34.49
19	24.99	20.00	0.00	13.79
20	50.00	25.00	22.73	31.03
21	24.99	0.00	22.73	15.51
22	31.25	0.00	22.73	17.24
23	0.00	0.00	18.17	6.89
24	24.99	20.00	0.00	13.79
25	0.00	25.00	22.73	17.24

*Mean percentage for each partial.

Table 37

Judges' Ratings of Clarinet Tones

Mean rating for each tone descriptor, and composite mean for each tone sample. A rating of "1" is superior to a rating of "5".

Sample	Mellow	Focused	Free	Full	Solid	Resonant	Clear	Rating*
1	2.63	2.96	3.10	3.28	3.16	3.13	2.87	3.02
2	2.23	1.80	1.74	1.57	1.62	1.56	1.79	1.76
3	2.31	2.08	2.41	2.40	2.66	2.36	2.20	2.35
4	4.32	3.44	3.17	2.59	3.26	2.96	3.29	3.29
5	2.26	3.20	3.24	3.46	3.09	3.11	2.67	3.00
6	3.96	2.97	3.52	3.07	2.99	3.04	2.46	3.14
7	1.96	2.62	2.57	3.09	2.84	2.74	3.04	2.69
8	2.19	2.18	1.84	1.69	1.96	1.71	2.31	1.98
9	2.51	2.44	3.07	2.87	2.89	2.77	2.62	2.74
10	3.73	3.17	3.32	2.83	3.21	3.02	3.10	3.20
11	2.42	2.79	3.13	3.72	2.94	3.02	3.01	3.00
12	3.50	2.72	3.27	2.90	2.87	2.98	2.81	3.01
13	3.40	3.56	3.77	4.22	3.61	3.79	4.16	3.79
14	2.44	2.52	2.56	2.28	2.47	2.22	2.30	2.40
15	2.04	1.99	2.29	2.47	2.09	2.30	2.11	2.18
16	2.40	2.03	2.11	1.91	1.87	1.99	2.06	2.05
17	2.46	2.53	3.10	3.62	2.81	2.96	2.73	2.89
18	3.59	2.88	3.13	2.62	2.93	3.44	3.11	3.10

n=16

*Composite Mean Rating for One Tone

APPENDIX C

Sample Profile Sheet for Judges' Ratings

Form A

Item No. ______

Circle the ONE number on EACH line which is closest to your subjective assessment of where the sample belongs.

1.	mellow	1	2	3	4	5	harsh
2.	focused	1	2	3	4	5	unfocused
3.	bright	1	2	3	4	5	dark
4.	full	1	2	3	4	5	small
5.	solid	1	2	3	4	5	spread
6.	resonant	1	2	3	4	5	nonresonant
7.	free	1	2	3	4	5	pinched
8.	clear	1	2	3	4	5	fuzzy