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AN ACOUSTICAL STUDY OF ALTO SAXOPHONE MOUTHPIECE CHAMBER DESIGN

Presented by

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To Fulfill the Dissertation Requirement for the Degree of

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VITA

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Mr. Wyman is well-known as a performer on the saxophone and as a clinician. In addition to performances in the Eastern United States, he has performed and given clinics in Iran, Colombia, and Indonesia.

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Special thanks are due Dr. Robert Gauldin and Dr. Paul Lehman of the Eastman School of Music for their suggestions in the preparation of the dissertation, and to Mrs. Theresa Barber who prepared the typescript.

ABSTRACT

This thesis is the result of a study made of the influence of the saxophone mouthpiece chamber design upon tone quality, intonation, and other playing characteristics. Its aim is to furnish information which will be helpful to teachers and performers in choosing an appropriate mouthpiece for a particular desired tone quality. The research is limited to investigation of alto saxophone mouthpieces.

Tests were conducted on twelve different designs. Measurements of each design were correlated with objective and subjective test results in order to isolate the effects of individual design parameters. Tone quality tests made use of spectrum analysis of selected tones from the range of the instrument. A Stroboconn tuner was used in making frequency measurements. The use of mechanical embouchures was avoided in order to duplicate actual playing conditions and to benefit from subjective reactions of the players taking part in the testing.

The major conclusions are concerned with the relative brightness of tone quality and the evenness of tone quality throughout the playing range of the instrument. The design factors responsible for these characteristics

are identified. Other premises are formed on intonation, mouthpiece resistance, dynamic range, and carrying power. Findings from the spectrum analysis indicate some new considerations for tone quality theory in the form of undamped and "accessory" harmonics which are not accounted for in presently held theories.

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INTRODUCTION

The saxophone was invented by Adolphe Sax (1814-1894) in or about the year 1840. Sax exhibited great insight in the area of acoustic design and with this knowledge he built, with conscious intent, a new instrument. In his patent application of 1846, Sax described the design of the saxophone mouthpiece. From Sax's careful attention to its description, it is clear that the mouthpiece was considered an integral part of the new instrument. It was designed to properly match the interior shape of the instrument body.

Since its invention, certain modifications in the saxophone's design have resulted in slight improvements while others have been detrimental to the original intent of Adolphe Sax. Changes in metal alloys and in the dimensions of the instrument's bore have resulted in modification of the tone quality and playing characteristics. A few improvements of the key mechanism have been made but it remains basically the mechanism which Sax designed. Largely due to demands for more volume and a more brilliant sound which could be heard above the screaming brass of large jazz bands, changes were made in the design of that part of the instrument which was most important in determining its tone quality--the mouthpiece. At present, the mouthpieces which are furnished with new instruments, as well as the array of different models on the market, are a far cry from the original design of Adolphe Sax. Many of the extreme changes in interior design result in a compromise in musical results. It has been the author's experience that these changes produce more volume and a more brilliant sound, but along with them comes less uniformity of tone quality throughout the range and an increase in intonation problems.

There is much confusion and ignorance among players and teachers of the saxophone concerning this vital subject. Selection of the proper mouthpiece seems to be based upon the "latest model" or the model which a particular performer uses rather than upon a musical evaluation of the results in tone quality and playing characteristics which a particular design produces. Most books of saxophone instruction give little factual information on specific dimensions of the mouthpiece and often suggest that a "medium chamber and medium lay" will be most satisfactory for the student saxophonist. They fail to give any hint about what a "medium chamber" is, so that virtually no help has been given in selecting a mouthpiece design.

The situation in the concert hall is equally discouraging. In a typical concert band, the brilliant, reedy sound of the saxophone section can usually be heard through, instead of blending with, the other woodwinds. Even though it has usually been reduced to a section of only four players, its reedy quality can still be heard when the saxophones are doubling the horns (one typical way that composers and arrangers try to hide them). There is often no effort made towards uniformity of tone quality through the use of similar mouthpiece chambers by all members of the saxophone section.

One would expect a little better result in the orchestral use of the saxophone. When the saxophone is used in the orchestra, usually a fine performer is available. However, occasionally the saxophone player uses a jazz type mouthpiece when a classical tone is required and an inappropriate tone results.

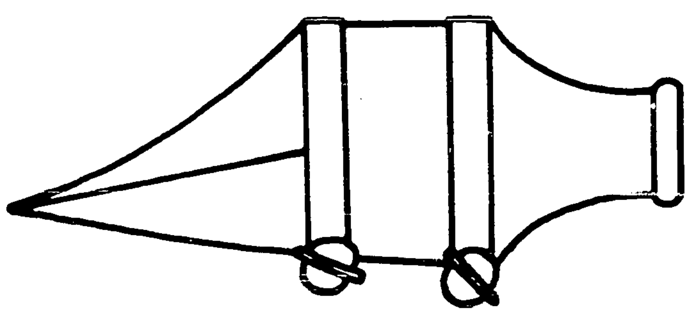
It is the purpose of this dissertation to furnish some knowledge on saxophone mouthpiece design which will aid the performer in selection of a design for his use which will most efficiently help to produce the tone quality and playing characteristics which he desires. To this end a series of tests was conducted to determine the extent to which the mouthpiece interior design was responsible for differences in tone quality, intonation problems, and related characteristics such as mouthpiece resistance, dynamic range, and carrying power. Chapter II describes in detail the experiments carried out. The study was limited to tests using alto saxophone mouthpieces.

CHAPTER I

THE HISTORICAL DEVELOPMENT OF THE SAXOPHONE MOUTHPIECE

In the patent letter, which Adolphe Sax filed in 1846 for his new instrument, is the sketch of the mouthpiece which is seen in Fig. 1.[1]

Fig. 1. Sax's Original Mouthpiece.



This is the mouthpiece for an instrument of the bass range. Sax goes on in the patent letter to state that the mouthpieces for the other sizes of saxophones are to be of the same proportions, although, if one wishes, they

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[1]The sketch from the original patent is reproduced in a letter from Sigurd Rascher to purchasers of the Sigurd Rascher Mouthpiece manufactured by the Buescher Division of H. and A. Selmer, Incorporated.

could be a little smaller or larger.[2] In his treatise on instrumentation (1844), George Kastner writes of the interior shape which Sax intended for the saxophone mouthpiece. His description stresses that its interior was very large and hollowed out.[3]

From the foregoing descriptions it seems clear that, although the saxophone mouthpiece was similar to that of the clarinet in its use of a single reed, it was different inside. The clarinet mouthpiece is characterized by straight side walls and a narrowing to a throat-like constriction.

Sax was not just improving an existing instrument, but with the insight of a gifted instrument maker's experience he built a new instrument. From his creative observations in the field of instrument acoustics he had been able to make many improvements in existing woodwind

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[2]Adolphe Sax, Letter of Patent for Saxophone, as quoted in Leon Kochnitzky, Adolphe Sax and His Saxophone (2nd ed.; New York: Belgian Government Information Center, 1964), p. 44.

[3]George Kastner, Supplement au Traité D'Instrumentation, as quoted in Lee Patrick, "The Saxophone," Instrumentalist, XXII (November, 1967), p. 74.

and brass instruments.[4] He sensed a weak area in the tone quality spectrum of the orchestral and band instruments of his time for which he intended to design a new instrument. It was probably not just trial and error that led him to combine a parabolic conical bore with the flexible, easily controlled single-reed mouthpiece.[5] His specifications on the interior shape of the mouthpiece must be assumed to be equally well thought out and in support of his intent for an instrument which combined the flexibility of the stringed instruments, the power of the brass instruments, and the color of the woodwind instruments of his day.[6]

Hector Berlioz, a contemporary of Sax, writes of the impression which he gained from first hearing the saxophone in 1842.

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[4]Adolphe Sax extended the range of the soprano clarinet downward by a half-step to the present e^b. He built a new bass clarinet radically different from the one then in use. In the field of brass instruments he designed a whole set of valved instruments whose ranges filled the gap which existed between the tubas and the cornets and trumpets. Kochnitzky, pp. 11, 13, 24.

[5]The sides of the conical bore of the original saxophone were not perfectly straight but had a slight parabolic curvature. Hector Berlioz, Treatise on Instrumentation (rev. and enl. by R. Strauss, 1904. Trans. by T. Front; New York: Edwin Kalmus, 1948), p. 399.

[6]Sigurd M. Rascher, "The Rational Saxophone," Woodwind Magazine, II (May, 1950), 66.

> . . . Its sound is of such rare quality that, to my knowledge, there is not a bass instrument in use nowadays that could be compared to the Saxophone. It is full, soft, vibrating, extremely powerful, and easy to lower in intensity. As far as I am concerned, I find it very superior to the lower tones of the ophicleide, in accuracy as well as in the solidity of the sound. But the character of the sound is absolutely new, and does not resemble any of the timbres heard up till now in our orchestras, with the sole exception of the bass-clarinet's lower E and F. Owing to its reed, it can increase or diminish the intensity of its sounds. The notes of the higher compass vibrate so intensively that they may be applied with success to melodic expression.[7]

This first instrument to be publicly demonstrated was a bass saxophone in the key of C.[8] Later, in his Treatise on Instrumentation, Berlioz refers to the whole family of saxophones:

> These newly gained orchestral voices have rare and valuable qualities. In the high range they are soft yet penetrating; in the low range they are full and rich, and in the middle range they are very expressive. On the whole it is a timbre quite its own, vaguely similar to that of the violoncello, the clarinet and the English horn with a half-metallic admixture which gives it an altogether peculiar expression.
>
> The body of the instrument is a parabolic cone of brass with a system of keys. Agile, suited just as well for rapid passages as for soft melodies and for religious and dreamy effects,

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[7]Hector Berlioz, "Adolphe Sax's Musical Instruments," Journal des Debats (June 12, 1842), as quoted in Kochnitzky, p. 13.

[8]Ibid.

> saxophones can be used in any kind of music; but they are particularly suited to slow and tender compositions.
>
> The high tones of low saxophones have a plaintive and sorrowful character; their low tones, however, have a sublime and, as it were, priestly calm. All saxophones, especially the baritone and bass, can swell and diminish their sound; this permits entirely new and quite peculiar sound effects in the extremely low range, which bear some resemblance to the tones of the "expressive organ". The sound of the high saxophones is much more penetrating than that of the clarinets in B^b and C without having the sharp and often piercing tone of the small clarinet in E^b. The same can be said of the soprano saxophone.[9]

The first mouthpieces were most likely made of wood. Sax had already constructed a metal clarinet mouthpiece as an improvement over the wooden ones then in use to add brilliance to the tone (remember that the clarinet in 1850 was not as bright as today's) and to alleviate the problems of warping caused by temperature and humidity.[10] He apparently preferred not to use this material for his new instrument. Since ebonite[11] was first used for the clarinet mouthpiece as early as 1851,[12] it is

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[9]Berlioz, Treatise on Instrumentation, p. 399.

[10]Kochnitzky, p. 13.

[11]Ebonite is a type of hard rubber.

[12]Walter L. Wehner, "The Effect of Interior Shape and Size of Clarinet Mouthpieces on Intonation and Tone Quality," (unpublished Doctoral Dissertation, University of Kansas, 1961), p. 25.

probable that saxophone mouthpieces were made chiefly of either wood or ebonite up to the twentieth century.

A little book written by A. A. Ross in 1928 called _The Saxophone Guide_ gives some clues as to the mouthpieces in use at the time of its publication. In a photograph, he shows five hard rubber mouthpieces. All of these mouthpieces are of the same general interior shape. The one which he considers to have the "most pleasing" results in tone was a stock mouthpiece manufactured by the Martin Company. He also discusses a couple of "extreme types" (hardly extreme at all by today's standards) as not generally satisfactory. Ross mentions materials used at that time. They include rubber, ebonite, glass, porcelain, metal, and a rubber mouthpiece with a metal facing.[13]

In a book written in 1938, mention is made of the similarity of clarinet and saxophone mouthpieces, but with the added observation that they are of different shape and size of interior chamber.[14]

Until the middle of the 1930s, saxophone mouthpieces seem to have been mainly of one general design with

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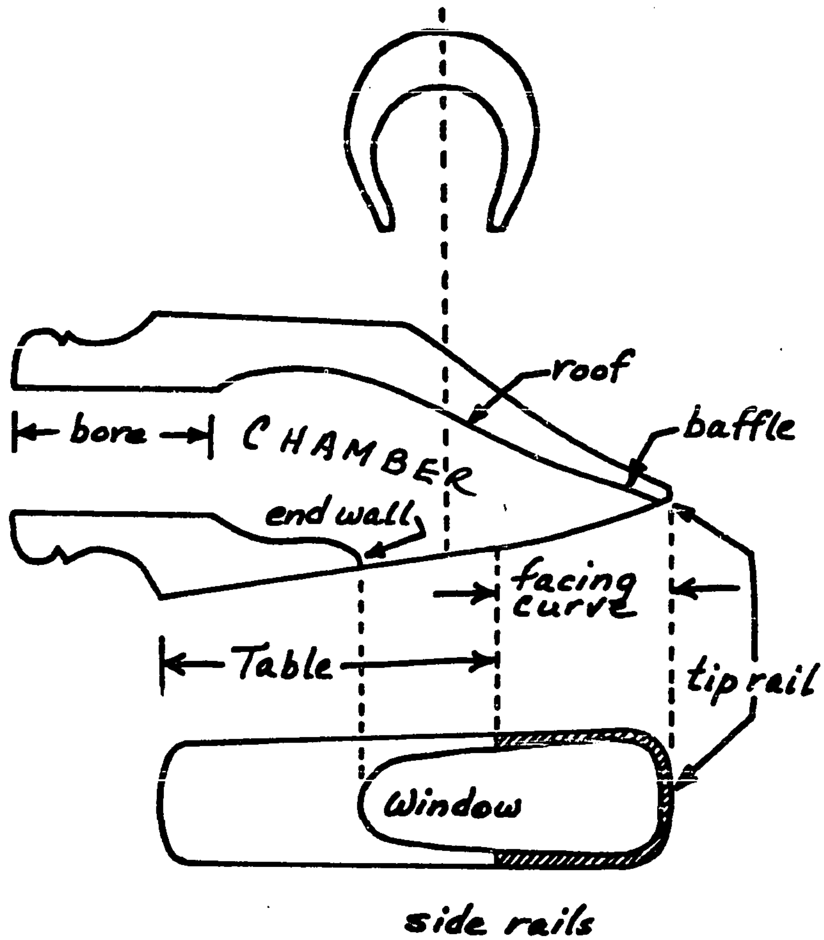
[13]A. A. Ross, _The Saxophone Guide_ (Boston: The Boston Music Co., 1928), pp. 17-20.

[14]Harry W. Schwartz, _The Story of Musical Instruments_ (Garden City, New York: Garden City Publishing Co., Inc., 1938), p. 147.

slight modifications in exact dimensions. A diagram of a Martin stock mouthpiece of that period with the various parts labeled may be seen in Fig. 2.

Fig. 2. Parts of Mouthpiece.



The parts are defined as follows:

BORE	--	that portion of the mouthpiece which fits over the corked end of the saxophone neck.
CHAMBER	--	the irregularly shaped interior of the mouthpiece from the opening of the saxophone neck into the mouthpiece interior to the inside edge of the tip rail.

ROOF -- the top of the mouthpiece chamber extending from the tip rail to the beginning of the bore.

BAFFLE -- that portion of the roof extending a short distance in from the inside edge of the tip rail. (The shape of this particular area is known to be critical in determining mouthpiece performance.)

TABLE -- the flat portion of the mouthpiece upon which the reed is secured by a ligature.

FACING CURVE -- also known as the "lay" of a mouthpiece. This is a curved extension of the table. It is in this area that the reed is free to vibrate in a transverse manner.

WINDOW -- the opening into the mouthpiece chamber, which lies under the reed, through which air enters the instrument.

SIDE RAILS -- that portion of the table and facing curve which forms the side boundaries of the window.

TIP RAIL -- the flat portion of the facing curve which is located at the tip of the reed and at the point of entry for the air stream.

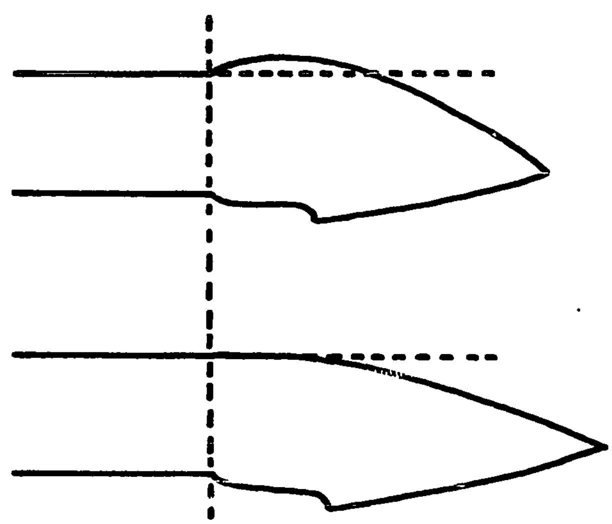
END WALL -- the inner end of the window.

From the cross-section views of Fig. 2 one can see that this original type of mouthpiece design has a round shape slightly larger than the bore at its point of maximum size and that the side walls of the chamber remain concave as the chamber narrows towards the tip rail.

What were the changes which took place in mouthpiece design? Because of its extreme versatility and expressive power, the saxophone has been called upon to play many roles. In the hands of an artist, it is capable of great expressive beauty, but it has also been called upon to portray the worst qualities--to make ugly sounds for their expressive power. Music used for entertainment (dance music) and later jazz, especially in its "heaviest" forms, has demanded brighter, edgier, and louder sounds until the original sound intended by Adolphe Sax has been changed radically. This development began in the early 1940's when dance bands began to increase in size and the saxophone section found that it was difficult to be heard over the increasing numbers of brass instruments. It was soon found that the greatest control over the brightness of the instrument's tone could be effected by changes in mouthpiece design. A certain amount of change can be brought about by changing reed contours but mouthpiece changes were more pronounced in their effect. At first, changes in facing length and tip openings were tried. Changes in the baffle shape, and, finally, changes in the complete chamber design were found to be more effective in achieving a more penetrating tone quality.

Until the turn of the century, mouthpiece chambers were of one basic type, varying in the extremeness of the maximum cavity size and to some extent in the length and roof contour as shown in Fig. 3. The maximum cavity size was however at least as large, if not larger, than the bore size.

Fig. 3. Variations in Roof Contour.



The first stages of the development of brighter designs continued the lowering and flattening of the roof contour and the reducing of the angle formed by the baffle and the reed. These changes to smaller elongated chambers took place around 1940.[15] Particularly in France, the

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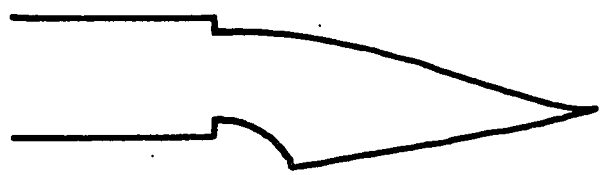
[15]Cecil Leeson, "The Modern Saxophone Mouthpiece," Instrumentalist, XV (October, 1960), 86.

lowering of the roof confirmation led to a new situation in which the transition from bore to chamber took the form of a constriction or throat-like opening instead of being an enlargement. Fig. 4 shows an example of this type.

Fig. 4. French Type.



This type of design was made with different sizes of throat opening. One explanation given for the advantage of this type of design was that the air going into the neck can do so without encountering any obstacle at the side thickness of the neck inside of the bore.[16] This is not the situation unless the neck touches the throat, which does not happen on any mouthpieces of this type that the author has examined. In position on the neck for proper tuning, there is always an enlargement between the throat

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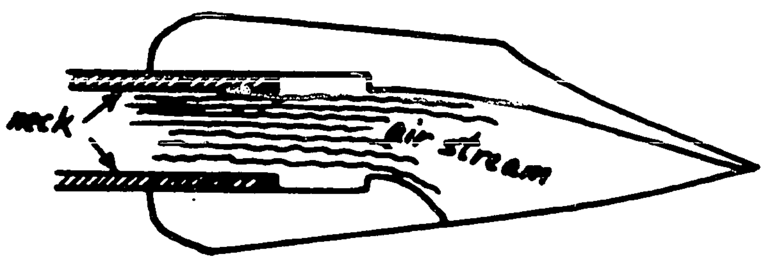
[16]Marcel Perrin, Le Saxophone, son Histoire, sa Technique et son Utilisation dans L'orchestra (Paris: Editions Fischbacker, 1955), p. 41.

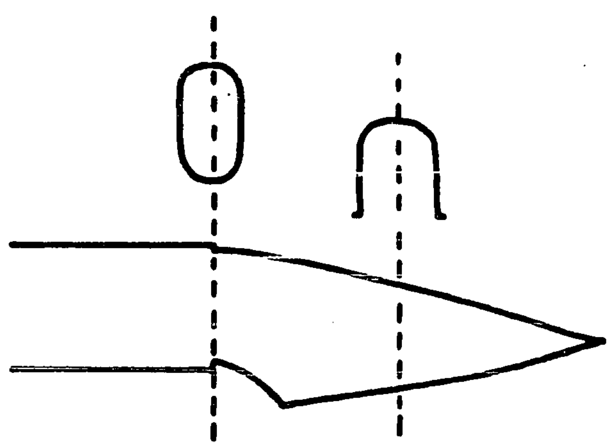
and the neck end as seen in Fig. 5.

Fig. 5. Throat and Neck Juncture.



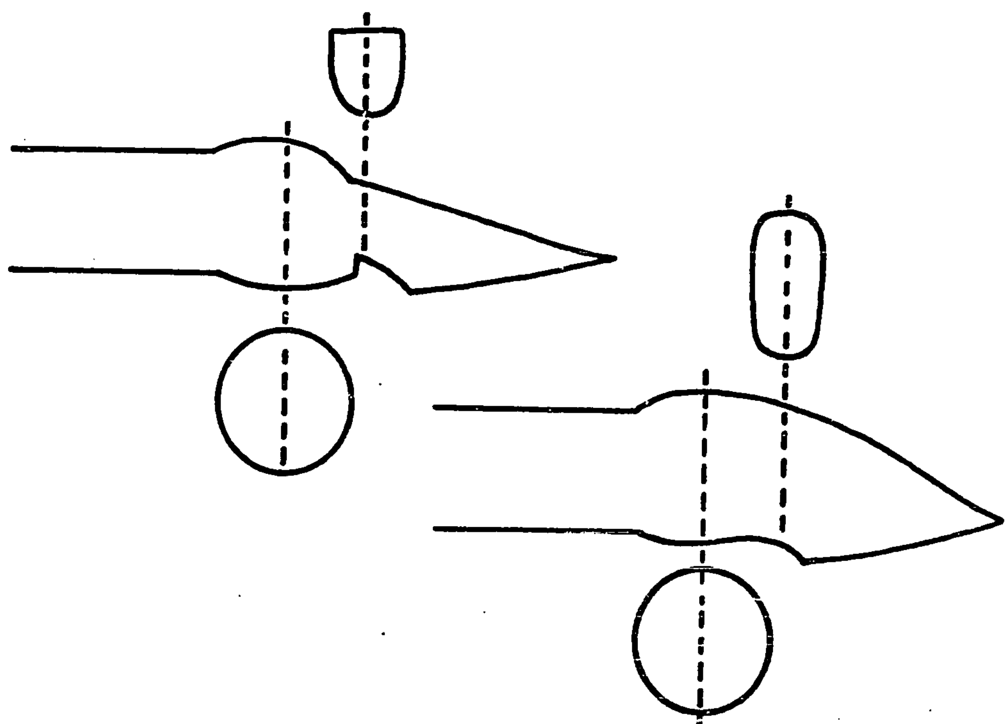
The next development in the chamber shape takes the form of a clarinet-like design in which the narrowing at the throat is an opening with straight side walls. These straight sides widen slightly toward the roof and continue straight in their path towards the tip of the mouthpiece as shown in Fig. 6.

Fig. 6. Clarinet Type.



Experimental mouthpiece designs using a double chamber were tried as early as the late 1930s.[17] These consisted of a larger-than-the-bore chamber and then a throat-like constriction. Two of these designs are shown in Fig. 7. The upper one is a Conn "Comet" model in which the throat area is very small and the roof contour very low.[18] The lower design is the "Meliphone Special" produced by the Woodwind Company. It has a throat of much larger area with a high roof contour which carries through into the large chamber inside. Both of these mouthpieces have straight sidewalls from the throat to the mouthpiece tip.

Fig. 7. Double Chamber Type.

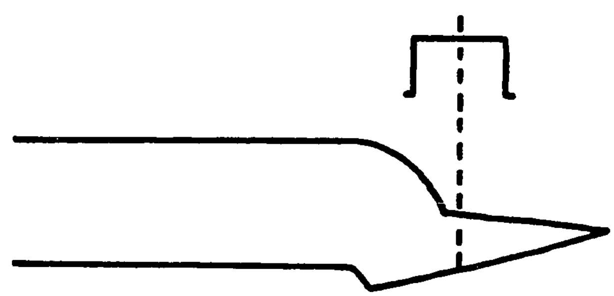


[17] William C. Willett, "The Evolution of the Saxophone Mouthpiece," Instrumentalist, XVI (June, 1962), 32.

[18] Ibid.

The most recent developments toward brighter types have omitted the double chamber and moved the throat closer to the tip of the mouthpiece--into the window opening area. The bore, extended down to this new throat location, becomes in effect the bulk of the total volume of the mouthpiece chamber. Fig. 8 shows a typical example of this general type. The baffle-to-reed angle is often very small in this type.

Fig. 8. Recent Type.



Therefore, through a series of modifications, the "old rounded 'tone chamber' has been choked by various flat surfaces and shoulders in order to give a brighter, more penetrating tone . . ."[19]

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[19]Anthony Baines, Woodwind Instruments and Their History, rev. ed. (New York: W. W. Norton and Co., Inc., 1963), p. 147.

Practical musicians are often ahead of the manufacturer in trying to make changes. Saxophone players often improvise alterations in mouthpiece chambers by the use of fillers of plastic wood.[20] Even chewing gum serves in a pinch. . well-placed wad of gum can bring the baffle and roof contour down with little work.

Although there are many "oddities" and patented experimental models, the types of chambers described above are those which have been manufactured in large quantities and which have found widespread use.[21]

Besides the design of the chamber itself, mention should be made of the advantages of the various materials used for mouthpieces. Two factors seem to determine the material used; (1) the ease of manufacture of the chamber and (2) the permanency of the facing curve. Wooden mouthpieces are difficult to keep from warping and the use of hard rubber is much more satisfactory in this regard unless extreme heat is a factor. Hard rubber is easily tooled and is the most popular material with performers. Glass, although very hard and not apt to warp at all, is brittle

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[20]Leeson, p. 86.

[21]Some experimental models are presented in the "Review of Acoustical Patents" section of the _Journal of the Acoustical Society of America_, XVII (1945), 99; XVIII (1946), 519; XIX (1947), 394; XXI (1949), 650; XXIII (1951), 402 and 619; XXV (1953), 598 and 599; XLVIII (1970), 1071.

and easily broken. It is difficult to produce glass mouthpieces with a large excavated chamber because this type cannot be readily molded and glass is difficult to work. Metals are next in popularity to hard rubber. Gold, silver, aluminum, brass, and stainless steel have all been used. Often they are plated and a rubber or plastic insert is almost always used on the outside where the teeth rest. The metal mouthpiece has the advantage of permanence of the facing, but it becomes cold very easily and moisture tends to condense on the inside more than with other materials. Ivory, porcelain, and plastics have also been used. Plastics in the easily molded chamber types are often used, especially for less expensive models.

Performers experience a difference in the "feel" of the different materials. This seems to be an important reason for the popularity of rubber mouthpieces. With the possible exception of ivory, rubber is the only material used which has the cellular structure of living matter. This very likely contributes to the vibrational characteristics of which the musician seems fond. Metals seem to have a harsh quality. Because of the extreme difficulty of making mouthpieces of identical design and precision dimensions with differences only of material, no accurate comparative study of materials has yet been made.

Studies by Sam Parker, on the tone produced by wooden and metal clarinets, have shown that the material has no apparent effect upon tone quality.[22] Even if the listener can discern no difference, the difference to the performer may be considerable. This difference in "feel" certainly has an effect on the way the performer plays.

The present lack of acceptance of the saxophone tone for use in the symphony orchestra and the tone quality and intonation problems it causes in the concert band are the result of a lack of the application of artistic values to the judgment of saxophone tone. It seems that the saxophone player is not taught to be as critical in matters of tone quality or intonation as other instrumentalists are. The matter of "blending" in bands and other ensembles has been hampered by the search over the past thirty years for a more brilliant sound. What has been gained in one direction has caused sacrifice in another. The mouthpiece chamber design is a critical factor in correcting these present-day shortcomings of the saxophone. Could certain designs be better able to add a bit of brightness to the tone without sacrificing much in evenness of quality

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[22] Sam E. Parker, "Analyses of the Tones of Wooden and Metal Clarinets," Journal of the Acoustical Society of America, XIX (May, 1947), 417.

throughout the range of the instrument and without causing intonation problems? This question will be answered in the chapters to follow.

There is not much definite information on saxophone tone quality to be gained from previous research. Of eleven books and periodical articles which include a spectrum analysis of saxophone tone, only one makes any mention of the mouthpiece used for the test.[23] Most articles fail even to mention which member of the saxophone family was tested. One such source uses the tone $\underline{g}^{\#}$ (209 Hz) for its example of saxophone tone without telling whether it is played on a soprano or a bass.[24] Another author selected for his example of saxophone tone a single tone played on a tenor saxophone--concert $\underline{b}^{b}$ (written $\underline{c}^{2}$ for the saxophone).[25] The use of a single pitch gives a far from complete picture of the tone quality of an instrument.

There is disagreement between researchers over the harmonic spectrum pattern of saxophone tone. One article

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[23]Cornelis J. Nederveen, Acoustical Aspects of Woodwind Instruments (Amsterdam: Frits Knuf, 1969), p. 106.

[24]Sir James Jeans, Science and Music (Cambridge England: University Press, 1947), p. 150.

[25]Charles A. Culver, Musical Acoustics (4th Ed., New York: McGraw-Hill Book Co., Inc., 1956), p. 143.

relates that there is no apparent pattern of overtone structure,[26] while another states that the saxophone has a well-balanced series of partials up to the sixteenth.[27] This poorly documented, conflicting information is hardly of much use. The sources with significant information relating to mouthpiece design will be referred to in subsequent chapters.

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[26]Harry F. Olson, Musical Engineering (New York: McGraw Hill Book Co., 1952), p. 224.

[27]Sigurd M. Rascher, "Thoughts About the Saxophone Mouthpiece," Instrumentalist, IX (October, 1954), 21.

CHAPTER II

TEST MOUTHPIECES AND TESTING PROCEDURES

Selection of Mouthpieces

This dissertation is limited to the alto saxophone since more mouthpiece types were available for that instrument. The author classified the many varieties of saxophone mouthpieces available according to basic types of chamber design. They fall into the following five classifications:

TYPE A   Original type with a chamber larger than the bore at its maximum size and with concave side walls.

TYPE B   Entrance from bore to chamber involves a constriction to a throat-like opening between the bore end and window opening. The side walls are slightly concave or straight.

TYPE C   Bore extended past window opening with constriction to low roof quite close to tip of mouthpiece; a common type of jazz mouthpiece.

TYPE D   Clarinet type of chamber with straight side walls.

TYPE E   Double chamber type.

For each of these classifications, a single mouthpiece was selected as being the extreme for its type. Thus, for Type A, a mouthpiece was selected having the largest chamber; for Type B, one with the smallest throat opening; for Type C, one with the smallest most constricted chamber; for Type D, the most typical of the straight-walled types; and for Type E, one with a large inner chamber and straight side walls.

In addition to these five basic mouthpieces, variations within some of the types were extreme enough to warrant the inclusion of one or two extra mouthpieces of the same basic type. Table 1 gives the names or designations given to the final selection of the twelve test mouthpieces.

Table 1. Mouthpiece Designations.

BASIC	VARIATIONS	
A	A-1	A-2
B	B-1	B-2
C	C-1	C-2
D	D-1	
E		

Diagrams of these twelve mouthpieces are found in Figs. 9 through 20. These diagrams are twice the actual size. A line extending down the center of the bore and

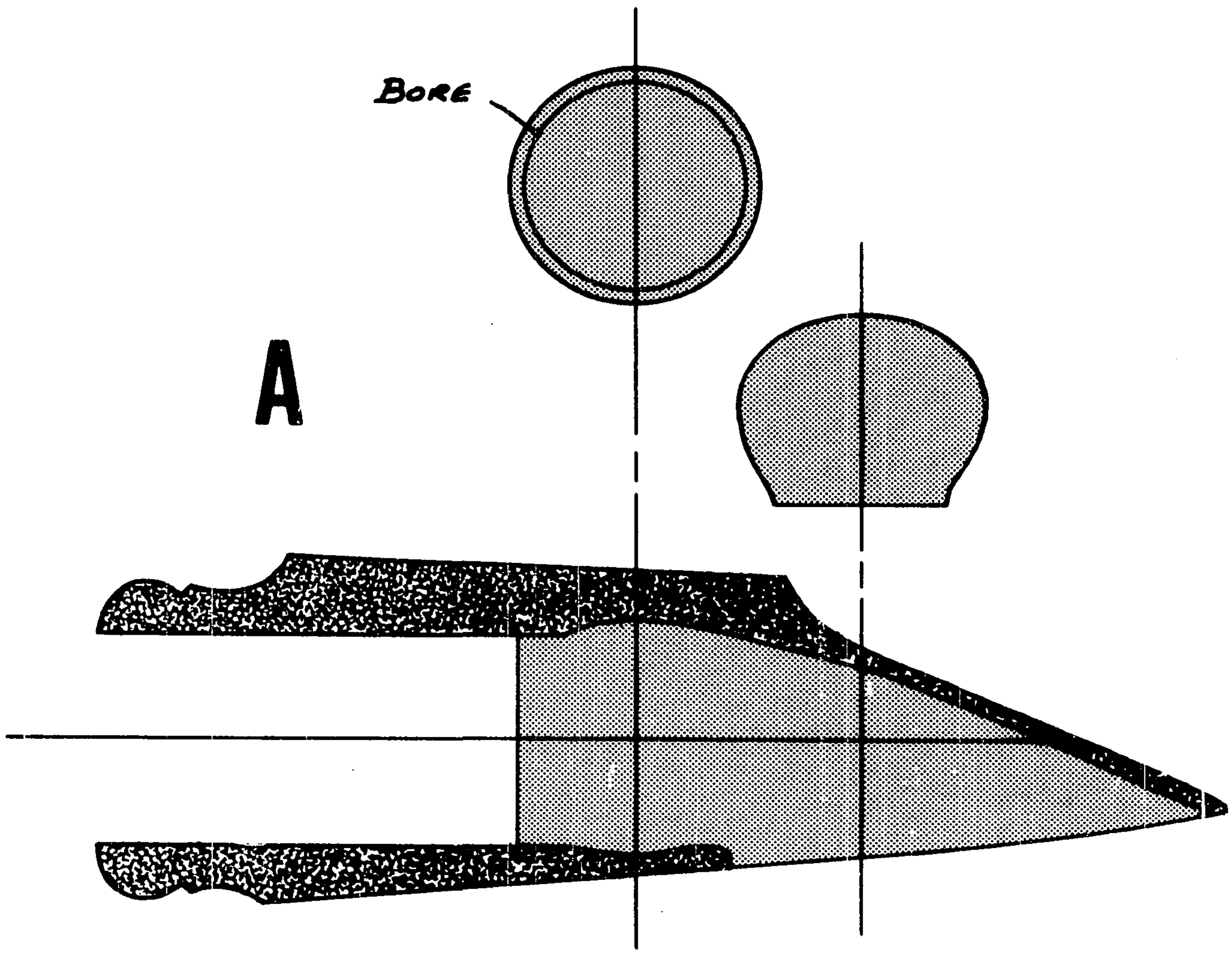


Fig. 9. Mouthpiece A.

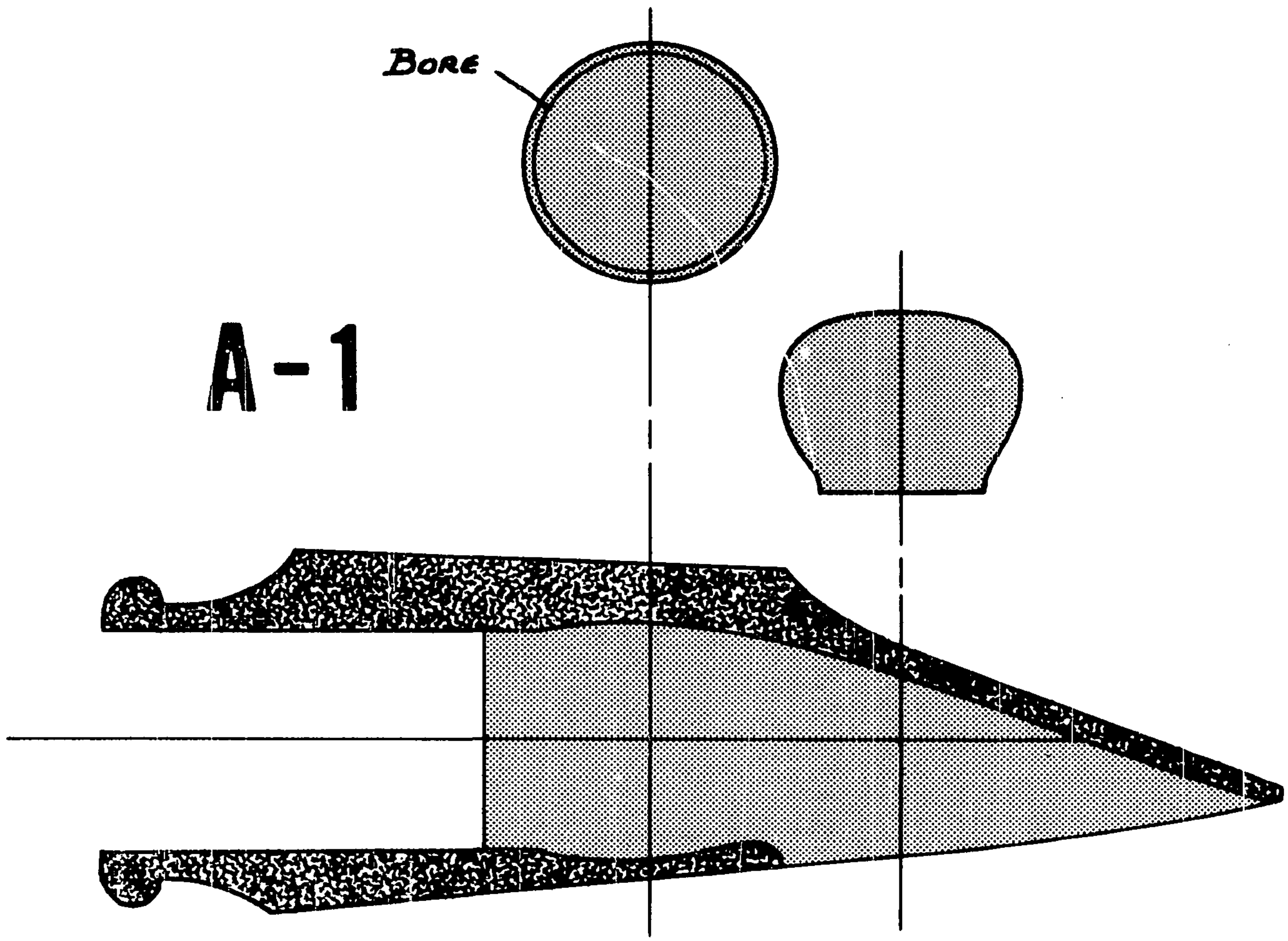


Fig. 10. Mouthpiece A-1.

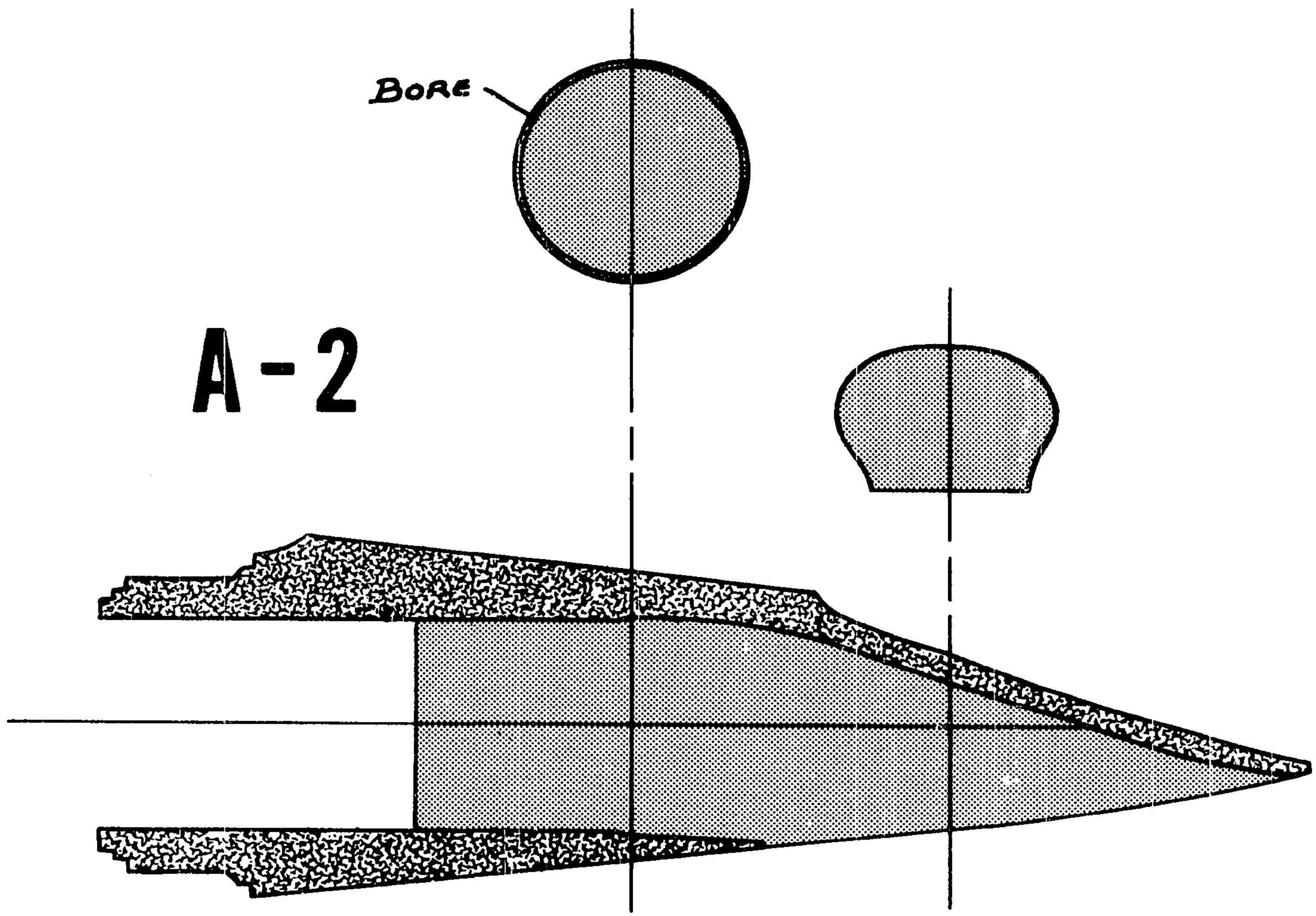


Fig. 11. Mouthpiece A-2.

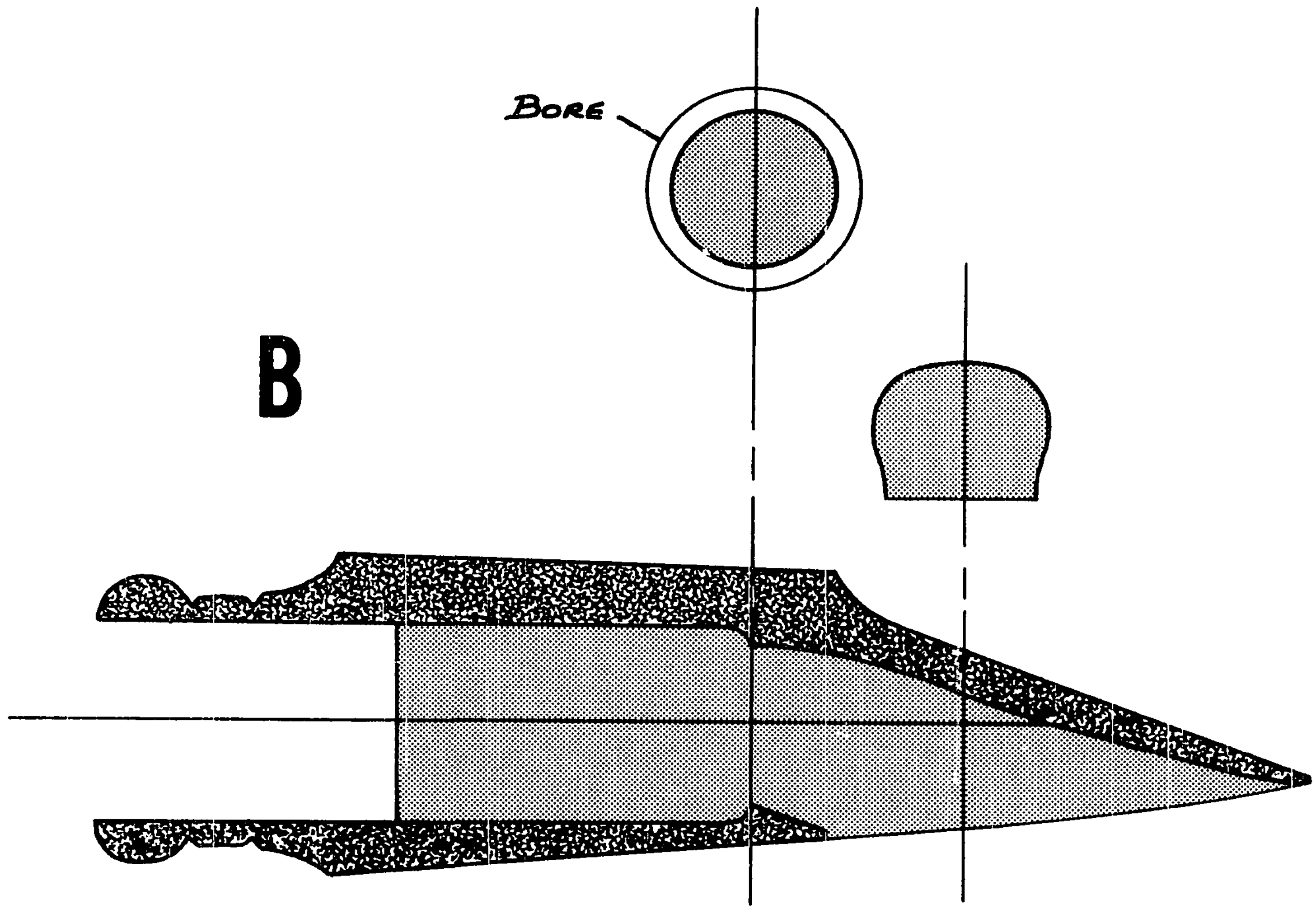


Fig. 12. Mouthpiece B.

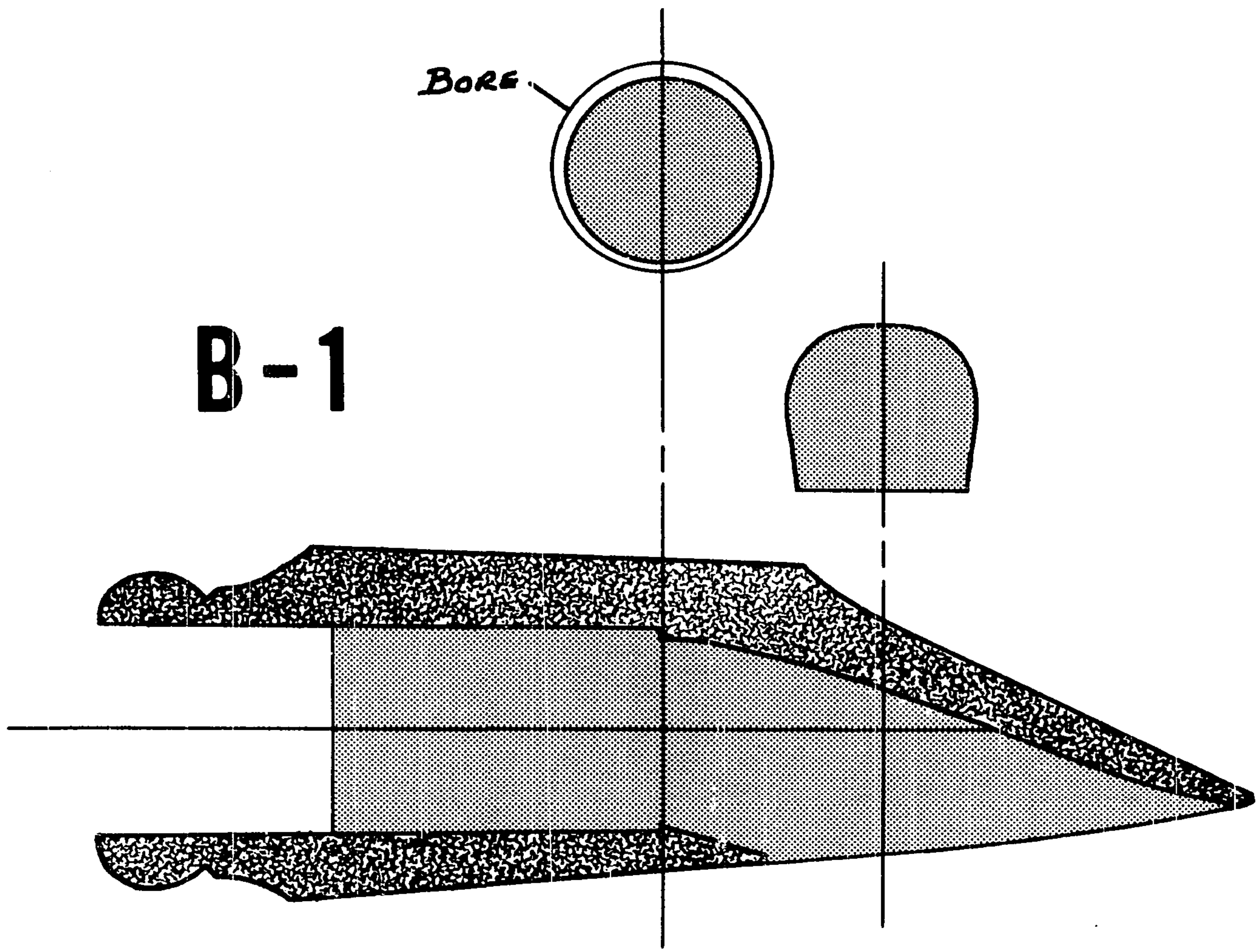


Fig. 13. Mouthpiece B-1.

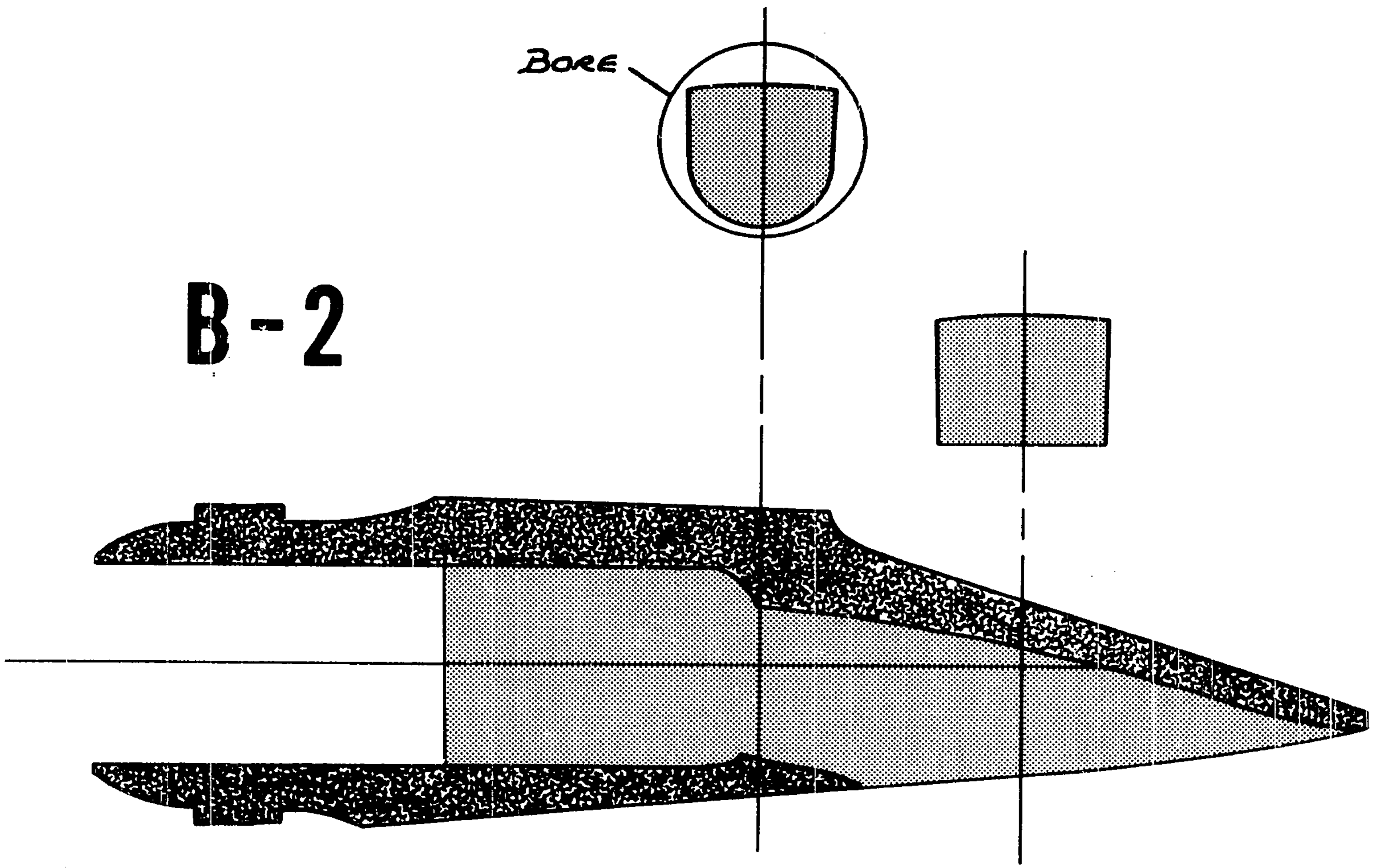


Fig. 14. Mouthpiece B-2.

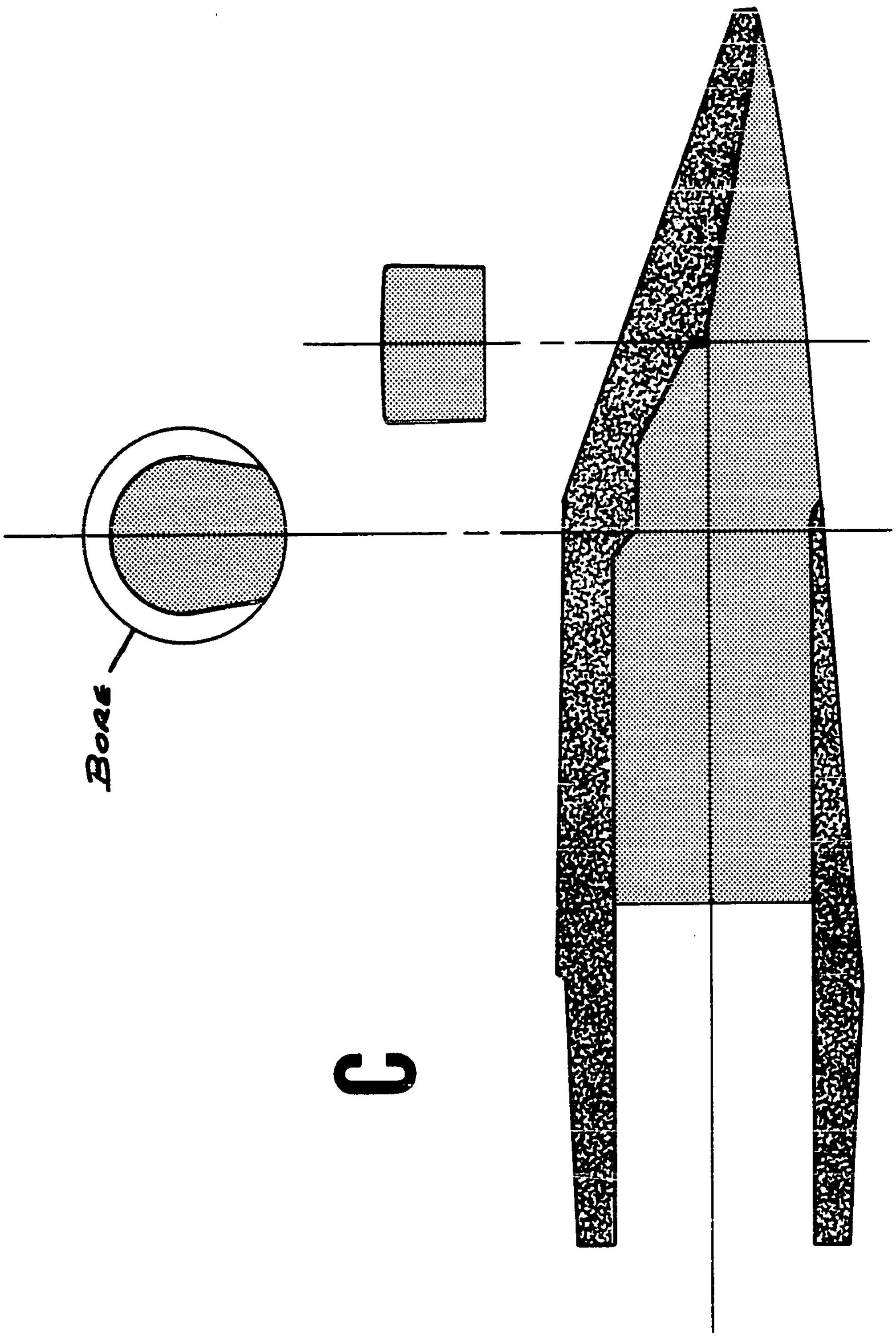


Fig. 15. Mouthpiece C.

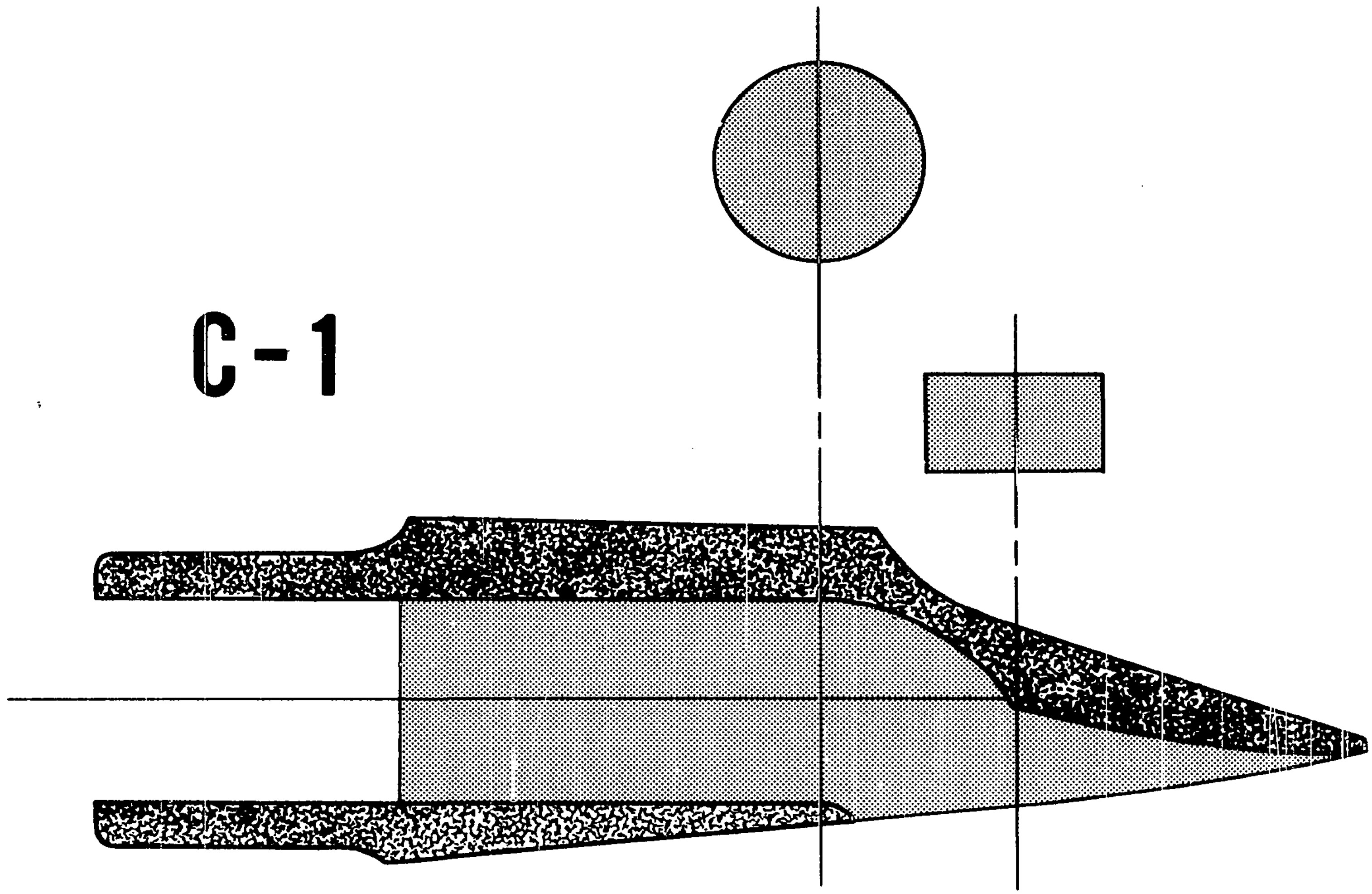


Fig. 16. Mouthpiece C-1.

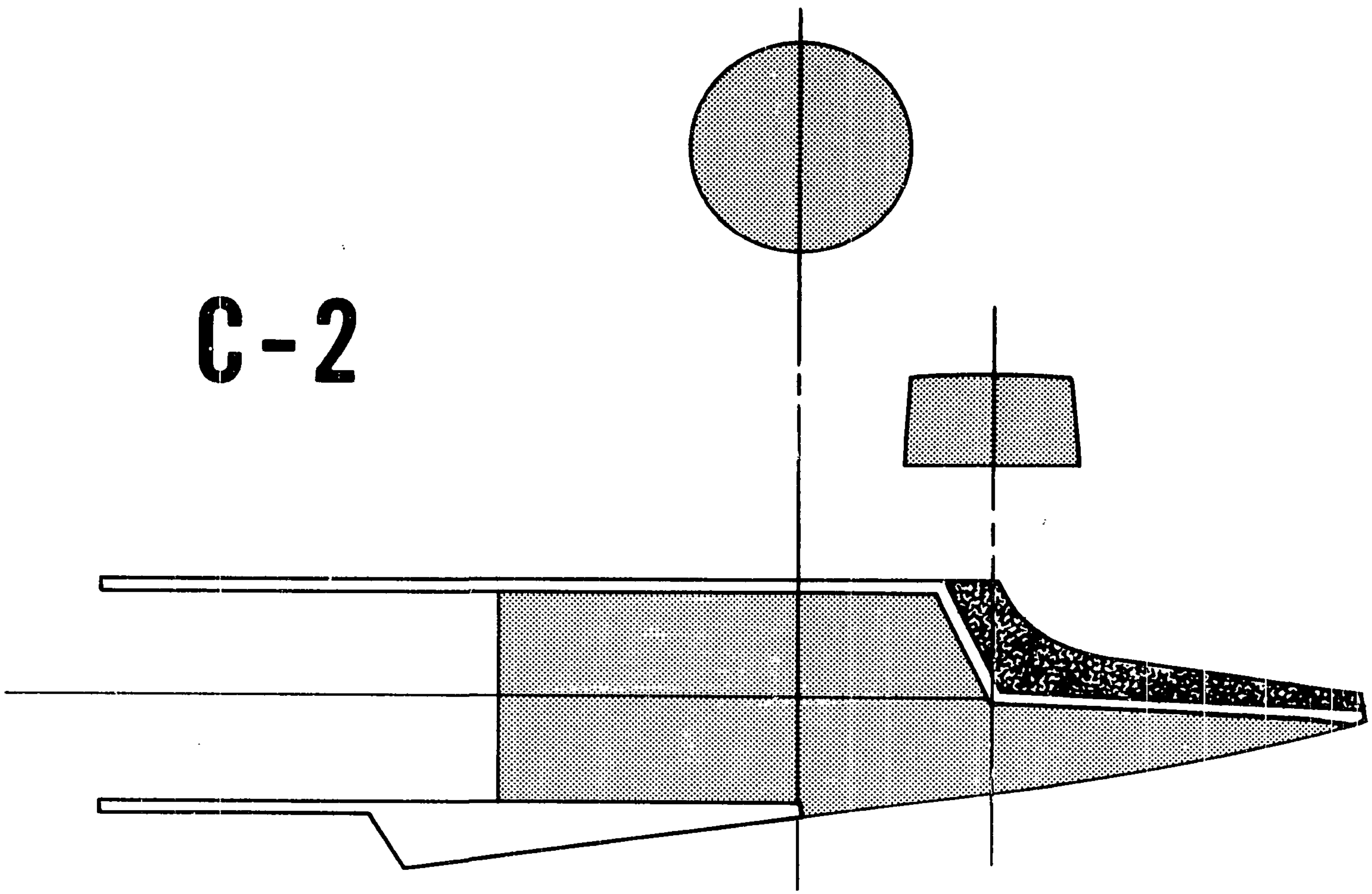


Fig. 17. Mouthpiece C-2.

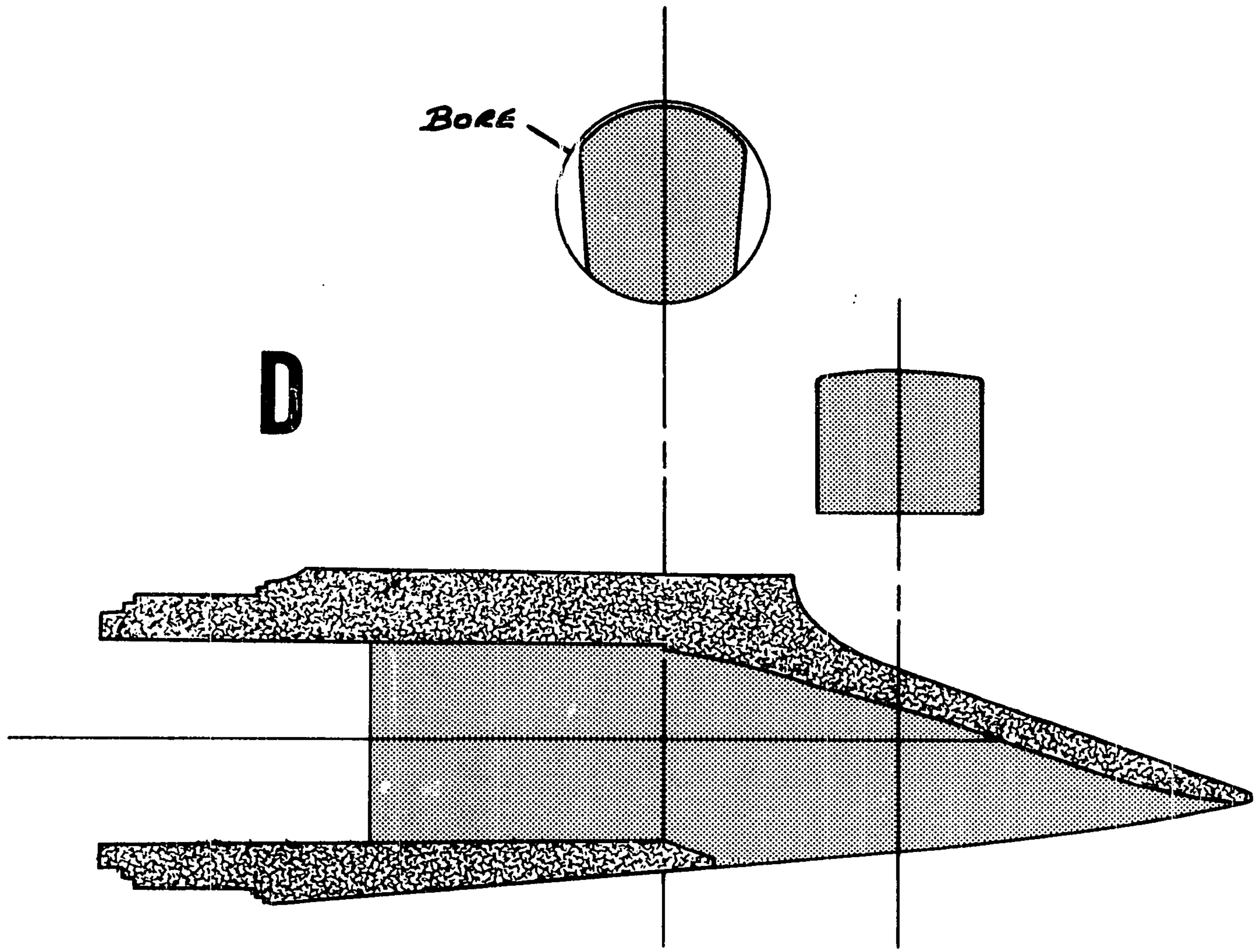


Fig. 18. Mouthpiece D.

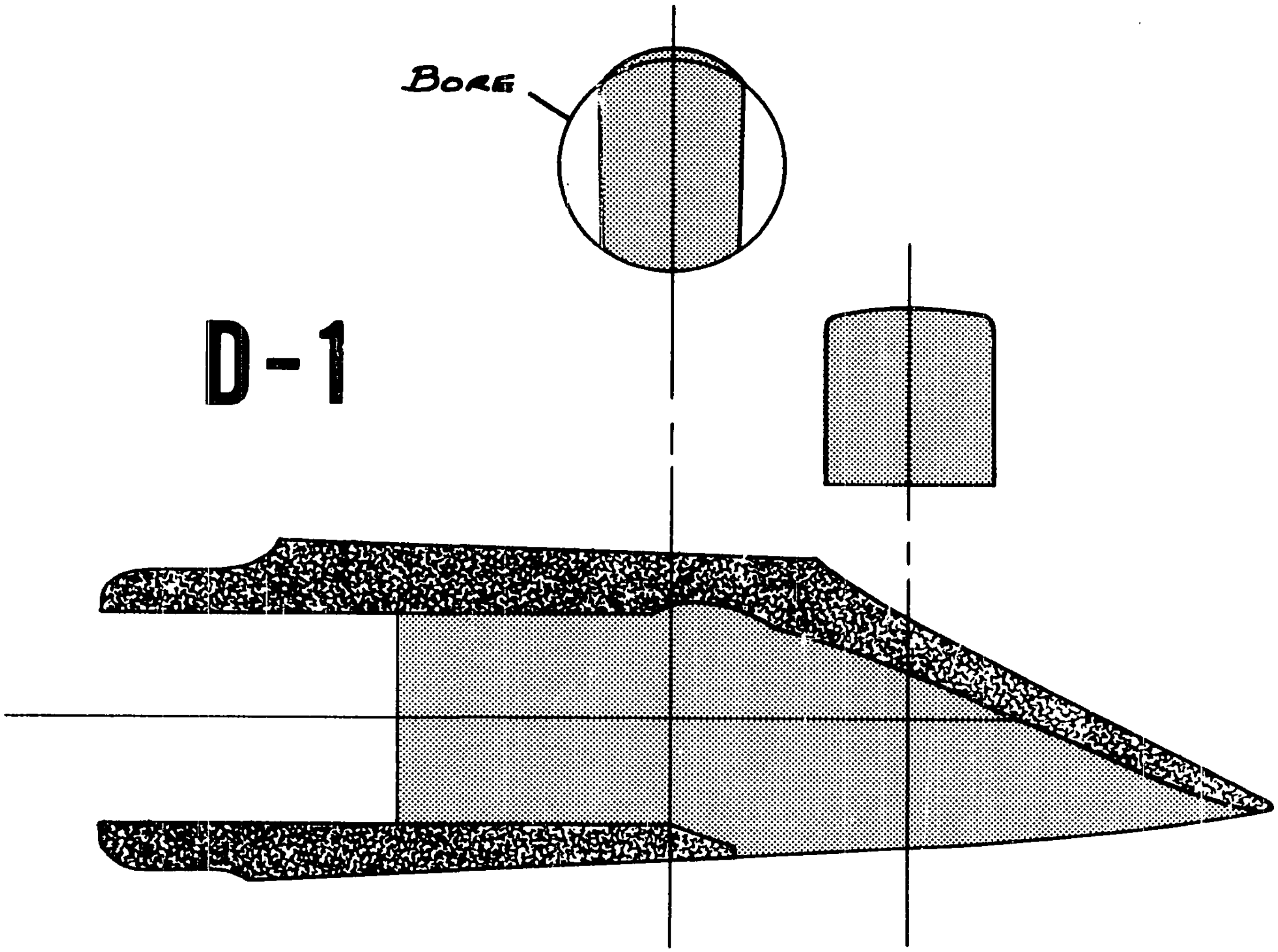


Fig. 19. Mouthpiece D-1.

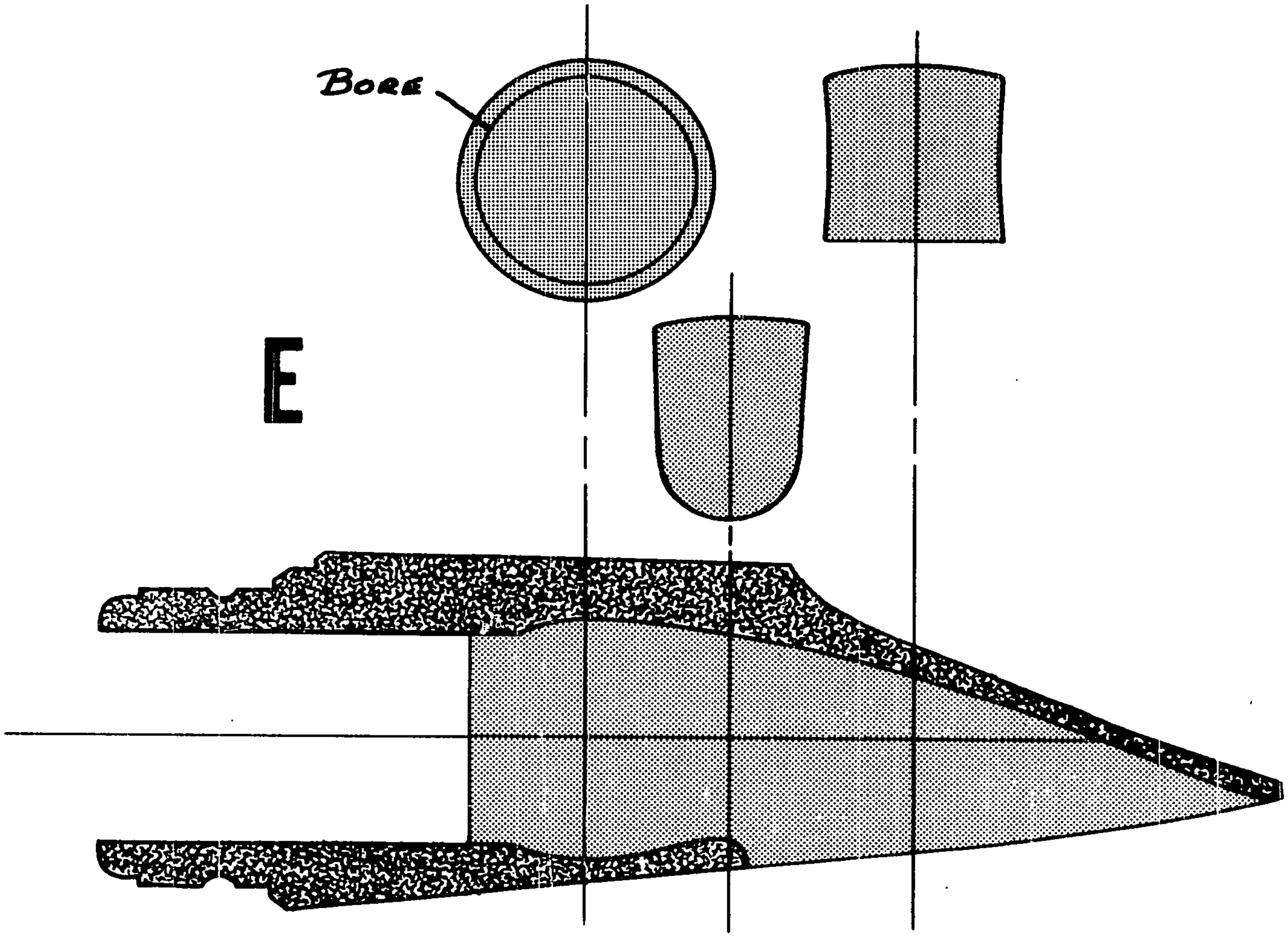
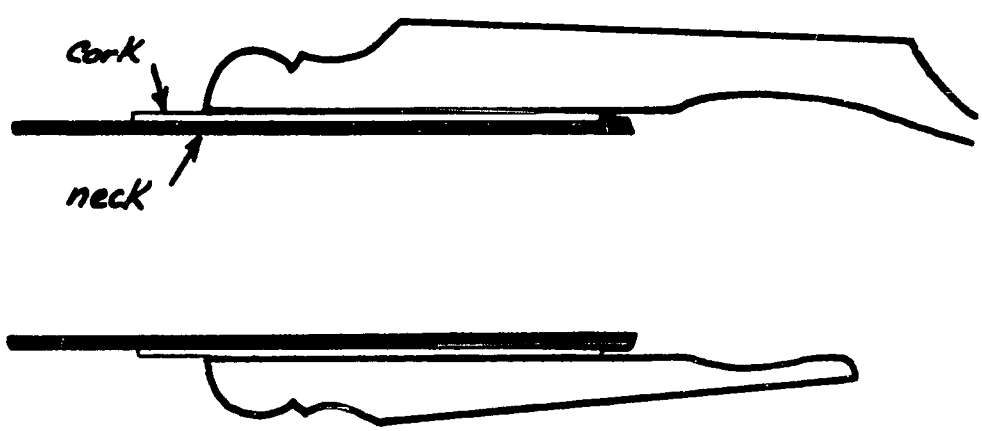


Fig. 20. Mouthpiece E.

continuing until it intersects the roof line has been added for making comparisons between mouthpieces. A line across the bore is placed at the exact point to which the end of the saxophone neck comes when the instrument and mouthpiece have been warmed up and properly tuned. This line is, of course, a simplification of the actual shape of the end of the neck. A diagram of the actual configuration at the end of the neck of the author's personal instrument is shown in Fig. 21. This drawing is twice the actual size.[1]

Fig. 21. Cross-section of End of Neck.



[1]Certain manufacturers have experimented in designs which attempt to eliminate the jog seen in Fig. 21 between the bore of the neck and the bore of the mouthpiece, but the increase in mechanical sophistication which was necessary is not matched by any apparent change in tone or playing characteristics.

The effective chamber shape and volume from the end of the neck to the tip of the mouthpiece is shaded in Figs. 10 through 21. Cross-sections of the chamber at the maximum chamber height or at the throat section, as applicable, are shown with a circle representing the bore circumference for comparison. Also a cross-section at a distance of one inch from the inside edge of the tip rail is shown for all mouthpieces. Appendix A (p. 127) gives the exact measurements of these test mouthpieces.

Mouthpiece A is the largest in maximum chamber height of this type. It is a Martin stock mouthpiece typical of those in use around 1935. Mouthpiece A-1 is a "Sigurd Rascher" mouthpiece currently manufactured by the Buescher Company. It has a maximum chamber height less than that of A and has a slightly longer chamber. This mouthpiece is the only one of the twelve test mouthpieces which is wider than it is high at its maximum point. Mouthpiece A-2 is manufactured by the Brilhart Company. It has the smallest maximum height of chamber (only slightly larger than the bore) and the longest chamber of the Type A mouthpieces. The shape of its end-wall is different from A and A-1.

Mouthpiece B is a Vandoran "perfecta" model. It has a small round throat constriction. B-1 is a mouthpiece (no brand name) manufactured in France having a slightly off-center round throat which is much larger than that of B but still not quite as large as the bore. Mouthpiece B-2 is a Selmer "Soloist" model. Its throat opening is small and irregular in shape. The roof is very flat from side to side at the throat opening.

Mouthpiece C is a Gomarico mouthpiece manufactured in Argentina. It has an irregular shape in the bore to roof area. C-1 is a Berg Larsen mouthpiece with larger bore area but a smaller tip area with an extremely small baffle-to-reed angle. Mouthpiece C-2 is a Brilhart "Level-Air" model selected for its unusually good playing characteristics for this type. It is most different in its large bore to table angle and in the unique relationship between the bore centerline and the low front roof.

Mouthpiece D is a Brilhart "Ebolin" model of the clarinet type with straight side-walls from the throat towards the tip. D-1 has no identifying marks. It was selected because of the extremely high roof contour for its type.

Mouthpiece E is a "Meliphone Special" of the Woodwind Company. It is a combination of Types A and D.

Most of the mouthpieces available on the market today are very close in design and measurements to one of the preceding twelve mouthpieces.

In addition to the twelve test mouthpieces, three extra mouthpieces of Type A were used in special testing of single areas of mouthpiece design. They are designated as mouthpieces W, X, and Y. Mouthpiece D was also later used for a later test of this type and is at that time designated as mouthpiece Z.

Preparation of Mouthpieces

The facing curve of a mouthpiece affects its playing qualities. Facing curves vary in three ways; (1) the length of the curve from the flat table to the tip rail, (2) the shape of the curve, and (3) the maximum opening at the tip rail. The effects of several types are as follows:[2]

LONG CURVE & CLOSE TIP	- favoring of low register, darker quality
LONG CURVE & OPEN TIP	- bigger tone
SHORT CURVE & CLOSE TIP	- reedy, stuffy tone
SHORT CURVE & OPEN TIP	- favors upper register, more penetrating quality

[2]Harold C. Luhring, "Factors Concerning the Construction, Selection and Care of Woodwind Reeds and Mouthpieces," (unpublished Master's Thesis, Illinois Wesleyan University, 1948), p. 12.

Each type of facing requires the matching of a reed of slightly different contour. The combined effects of these two matched variables can greatly affect the way a mouthpiece responds to the player. In order to reduce these factors to a minimum in the comparative study of the internal design of mouthpiece chambers, all of the mouthpieces used in the study were refaced by hand by the author to identical facing curves. The tip and side rails were also matched as closely as possible for all of the mouthpieces. These are about 1/32nd of an inch in width. Too much width in the rails results in a heavy, dull tone and difficulty in rapid articulation while rails that are too narrow tend to make the tone reedy and brighter with, however, a better response in rapid articulation.[3]

The facing which was put on these test mouthpieces is that used by the author. This facing, or one very close to it, is also used by all of the players participating in the testing. The most popular system of defining the facing curve is that devised by Erick Brand.[4] In this

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[3]Ibid., p. 23.

[4]Erick D. Brand, Band Instrument Repairing Manual (Elkhart, Indiana: Erick D. Brand, 1946), pp. 120-24.

system, thickness gauges of various sizes are inserted between the mouthpiece curve and a flat glass plate upon which the mouthpiece table rests. They will slip under the curve until the distance from the curve to the table plane is the same as the thickness of the gauge. The length of the curve is the distance to which a gauge of .0015 inch thickness will slip in before stopping. These distances are measured in 1/2 millimeter units. The facing used on all of the test mouthpieces would be described as having a medium length and medium tip opening and are found in Table 2.

Table 2. Facing Measurements.

Thickness of Gauge	Distance in 1/2 mm. units from outside edge of tip rail
.0015"	41.5
.0100"	30.5
.0240"	20.5
.0340"	14.5
.0500"	8.0

There are slight variations in the exact tip opening from mouthpiece to mouthpiece. The opening between the inside edge of the tip rail and the plane of the table varies from .0600 to .0660 inch between mouthpieces.

The mouthpiece bores were all reamed to the same size so that they would all fit easily on the corked end of the neck. The old Martin mouthpiece (A) was originally manufactured with a purely cylindrical bore of 5/8 inch diameter (.6250"). Other mouthpieces, particularly older models, had smaller bores. Many of them had a slight taper in the bore (becoming smaller towards the chamber end). Because of the convenience of obtaining a reamer to make a 5/8 inch cylindrical bore, this was selected as the bore for all mouthpieces. If a mouthpiece had a taper which became smaller than that size, then the reaming was done only as far as needed for the correct placement of the mouthpiece on the neck cork. The Type A mouthpieces were reamed all the way to the bore end. All of the reaming was done using a 5/8 high-speed steel drill, the mouthpiece being turned by hand over the stationary bit.

Measurement of the Mouthpieces

Measurements of the chamber design were taken of the following parameters:

1. Density of the Material
2. Volume of the Chamber
3. Window Length and Width
4. Bore length
5. Bore taper
6. Chamber length--end of neck to inside edge of tip rail
7. Baffle and Roof shape
8. Roof Thickness

9. Opening of mouth necessary in playing mouthpiece

10. Angle of the Bore to the plane of the Table

11. Inner-chamber Maximum Height and Width

See Appendix A (p. 127) for these measurements for the test mouthpieces.

Critical linear measurements were made with calipers and a Starrett micrometer to the nearest 10 thousandth of an inch. Density was determined by a water-immersion method finding the mass per cubic centimeter of material. Chamber volume was measured by plugging the mouthpiece to the neck line and filling the chamber with water. The measured volume of this water indicated the volume of the chamber. Measurements of window width were made at two points; at the tip rail and at a distance of one inch from the inside edge of the tip rail.

To establish the exact contour of the roof and baffle, a special tool was constructed which allowed the author to make measurements of the distance between the table plane and the roof at certain fixed distances from the inside edge of the tip rail. This tool may be seen in Fig. 22. The mouthpiece is affixed to the device in such a way that, by removing small blocks one at a time, the mouthpiece will slide forward and lock in place for the next measurement position. The measurement positions

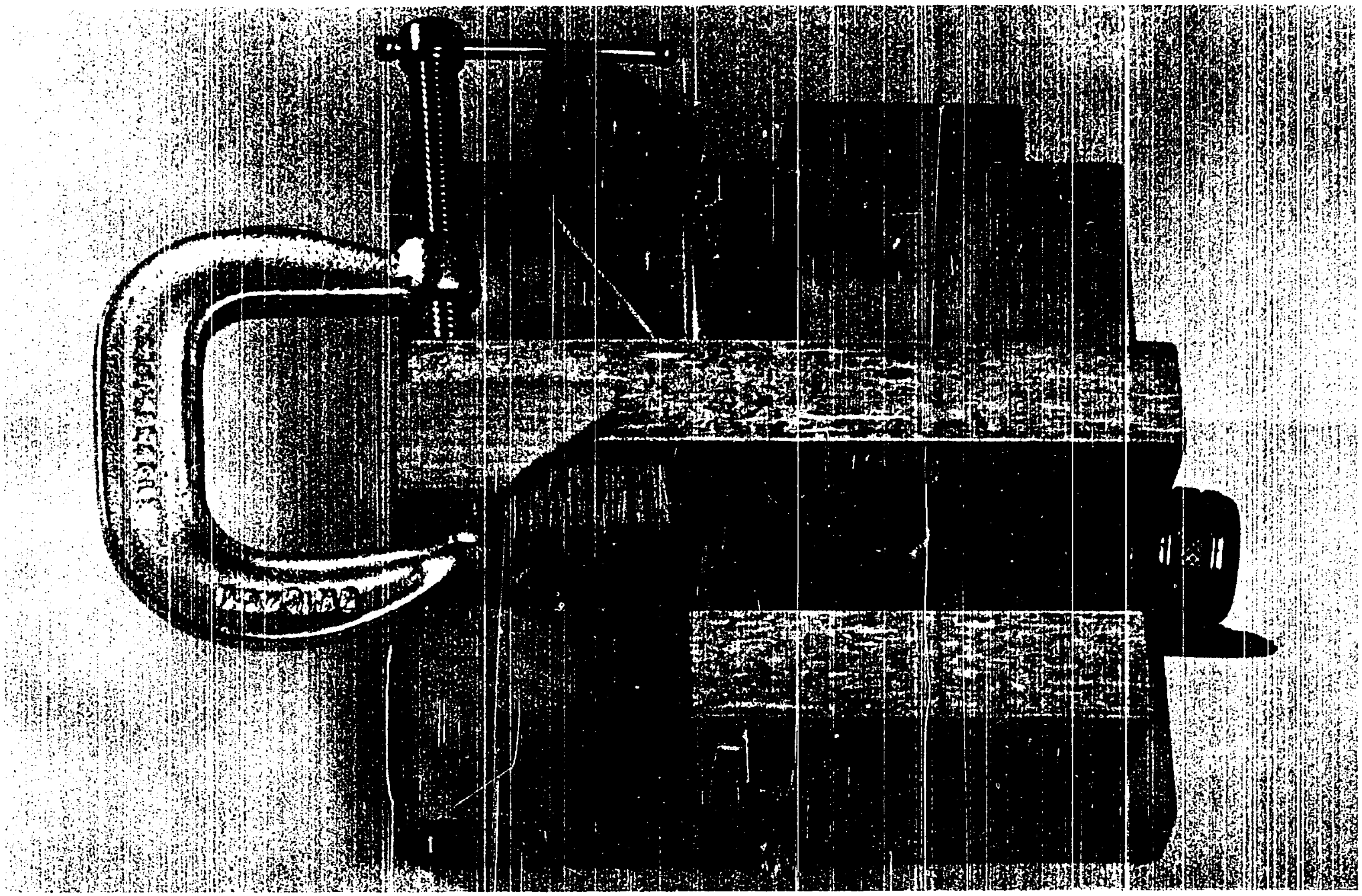
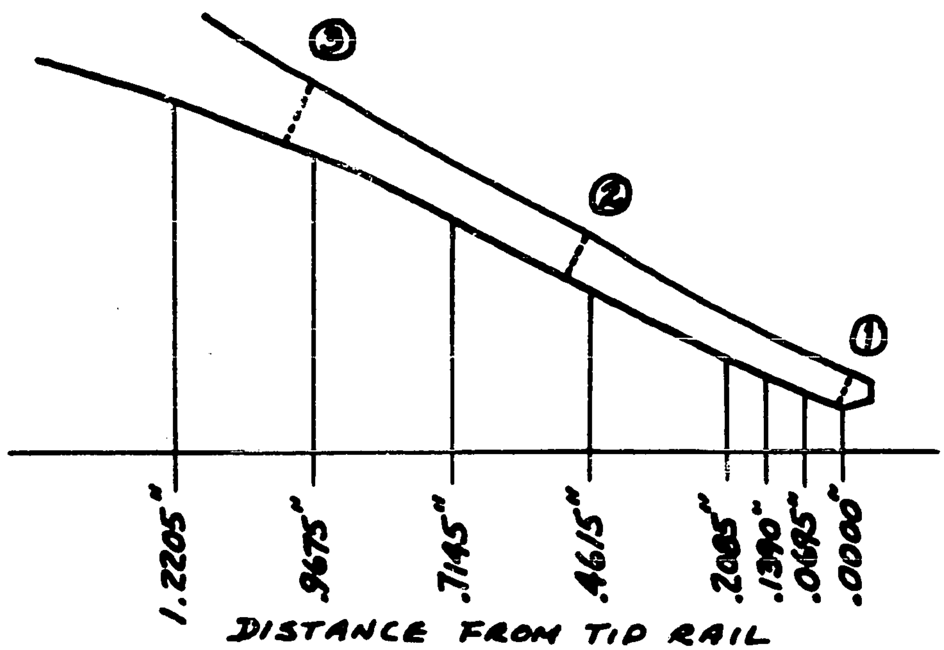


Fig. 22. Tool for Measuring Roof Contour.

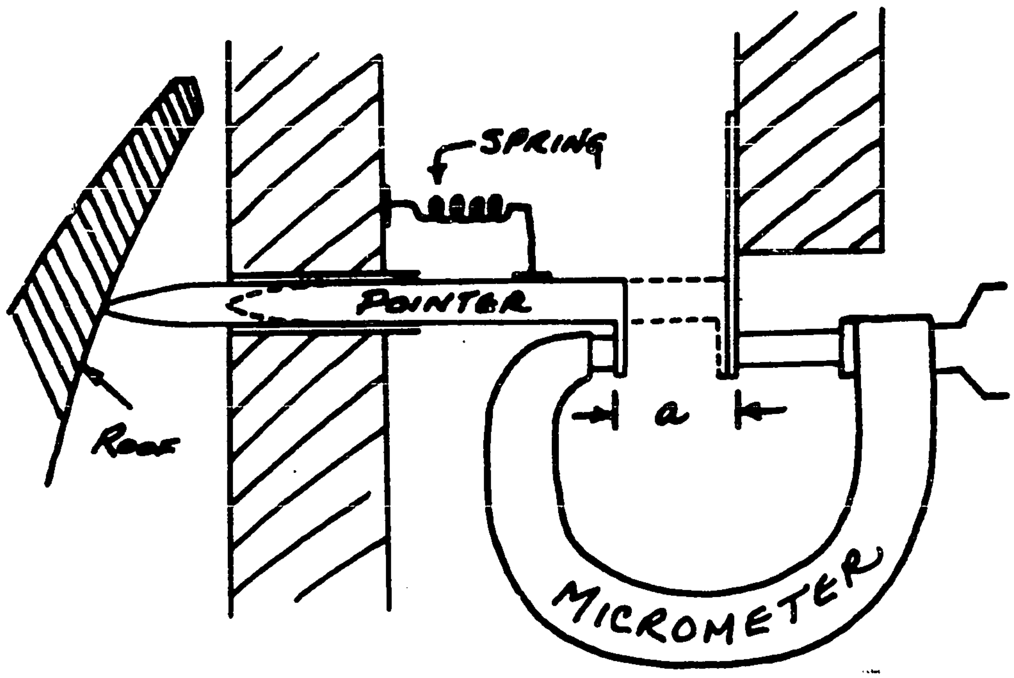
are closer together for the first few measurements so that the critical area of the baffle can be more precisely defined. These positions are shown in Fig. 23.

Fig. 23. Measurement Positions for Roof Contour.



The measurement is made with a spring-loaded pointer which touches the roof as shown in Fig. 24. The distance "a" minus the thickness of the two tabs gives the height of the roof at that point.

Fig. 24. Spring-loaded Pointer.



The thickness of the roof was measured at points marked 1, 2, and 3 in Fig. 23 above.

The measurement of the bore-to-table angle was carried out on another home-made device shown in Fig. 25. The device is adjusted in the bench vise so that the shaft upon which the mouthpiece is mounted is level and the pointer is on the zero degree mark. The level is then placed upon the mouthpiece table and the shaft raised until the table is level. The pointer then indicates the bore-to-table angle in degrees.

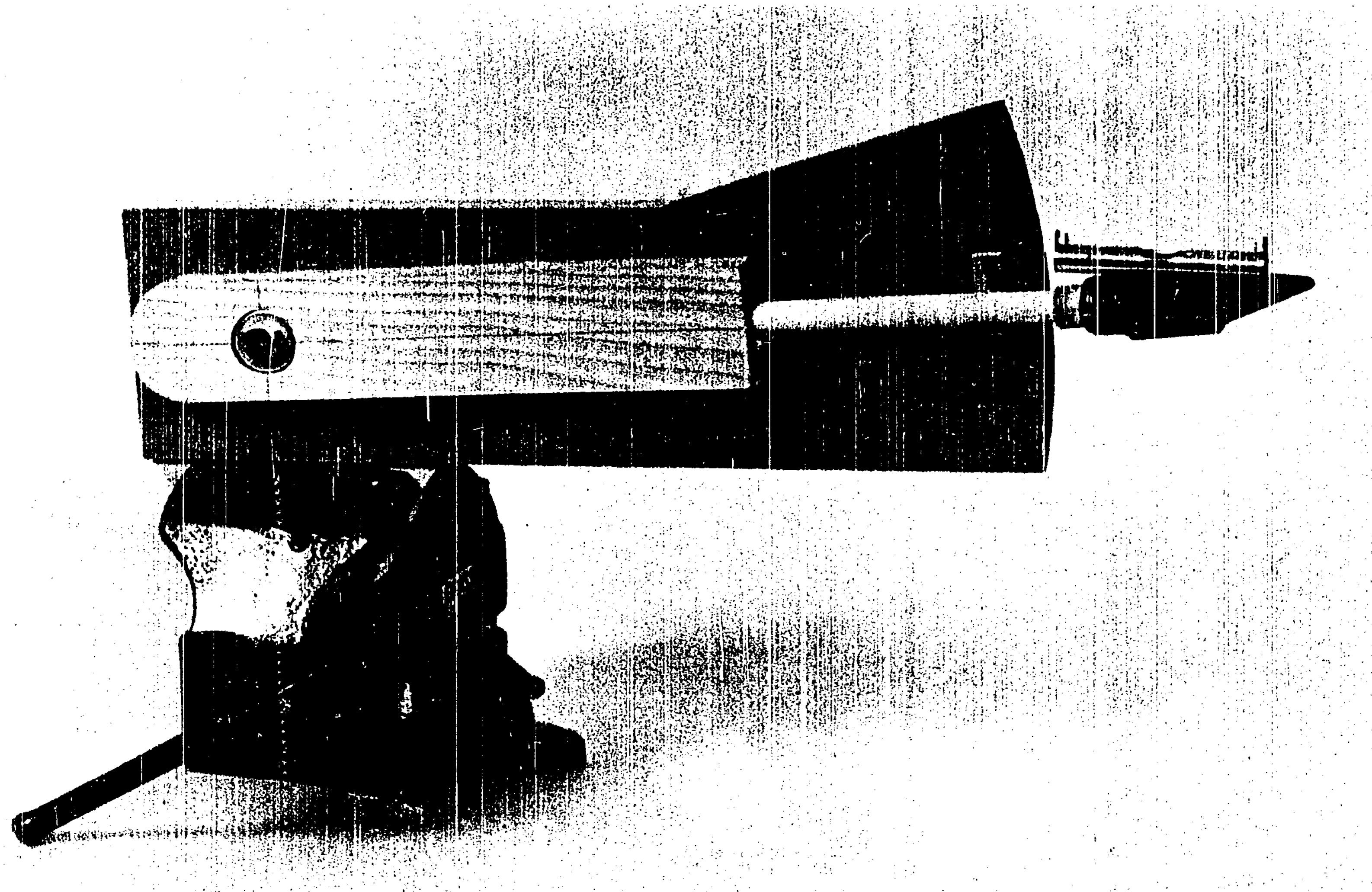


Fig. 25. Tool for Measurement of Bore-to-table Angle.

Procedures Used in Testing

The testing of effects caused by different mouthpiece designs was done under ordinary playing conditions, as much as possible. Some acoustical studies of musical instrument tone rely upon mechanical embouchures in an effort to remove the human element. There is a big difference between the sound of a live, humanly-blown tone and the unmusical mechanically produced tone. The human element seems, in fact, to be the biggest factor in the production of a "musical" tone on any musical instrument. Many of the differences between mouthpieces are of the nature of subjective differences in the "feel" of the mouthpiece. There are certain areas of investigation which are best carried out in a purely subjective manner by the performer. Objective testing of the intonation characteristics of each mouthpiece was carried out with the aid of a Stroboconn tuning device. Objective analysis of the tonal spectra produced by the test mouthpieces was carried out on a spectrum analyzer.

Test 1

The first tests to be carried out were subjective analyses of tone quality and playing characteristics. The players taking part in these tests were eight of the author's advanced saxophone students at the State University College at Fredonia. The form used for the player evaluation and the instructions for taking the test are to be found in Appendix B (p. 134). This test was a comparison of only the five basic mouthpieces (A, B, C, D, and E). The test aimed at making subjective judgments and comparisons between these five mouthpieces on the following criteria:

1. General tone quality
2. Evenness of tone quality throughout the range
3. Resistance
4. Dynamic range
5. Tonguing characteristics
6. Agreement in pitch between overtones of the lowest fundamental of the instrument and their fingered pitches
7. Ease of slurring across "breaks" - from one mode of vibration to another

Test 2

Immediately after completing the above test, each player also conducted an intonation test with the same five mouthpieces. The instructions for this test are also found in Appendix B. The eleven tones used for this test were carefully chosen to include notes which generally tend to be out of tune on the saxophone. They cover a three-octave range. They are shown in Fig. 26 as they are written for the E^b alto saxophone.[5]

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[5]The alto saxophone is a transposing instrument. Written pitches are a major sixth above the actual sounding pitches.

Fig. 26. Test Pitches.

They were played in ascending, descending, and in a mixed-up order to average out tendencies of the player to play intervals in tune. An assistant was used during the Stroboconn tests for recording the sharp and flat deviations in cents[6] from the correct frequency for each pitch. Each subject used his own saxophone for his part in the testing. The instruments were all Selmer alto saxophones; however, some of them varied considerably in bore shape and in the metal used (earlier models). The serial numbers were as follows:

14,600
25,812
94,135
101,566
112,899
133,933
141,500
173,322

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[6]One cent is equal to one-hundredth of a tempered half-step. There are 1200 cents in an octave.

The author also carried out these same subjective tests and the Stroboconn intonation tests, but did them for all twelve of the test mouthpieces. The author's instrument is a Selmer (serial number 21,182).

Test 3

One additional test was carried out by the author in connection with the intonation testing. This was a test to see if different mouthpieces caused different amounts of pitch deviation with changes of dynamic. The tone $\underline{f}^2$ was played at a pianissimo and at a fortissimo level in addition to the mezzoforte level prescribed in the other intonation testing for this purpose. All of the testing mentioned thus far was carried out in the author's teaching studio.

Test 4

The next series of tests were connected with the spectrum analysis of the tones produced by the different mouthpiece designs. For this purpose the author recorded tones on magnetic tape for each of the twelve test mouthpieces. The tones selected are the same tones as were used for the intonation tests. To make possible a careful study of formant regions in the saxophone tone, the five basic mouthpieces (A, B, C, D and E) were recorded for all eleven tones. The seven variant types were recorded using only the six tones shown in Fig. 27 in an effort to cut down on the large number of tones to be analyzed.

Fig. 27. Test Pitches.

Test 5

In order to test the effect of dynamic change on tone quality, test tones at pp and ff levels were also recorded for the note f^2 on the five basic mouthpieces.

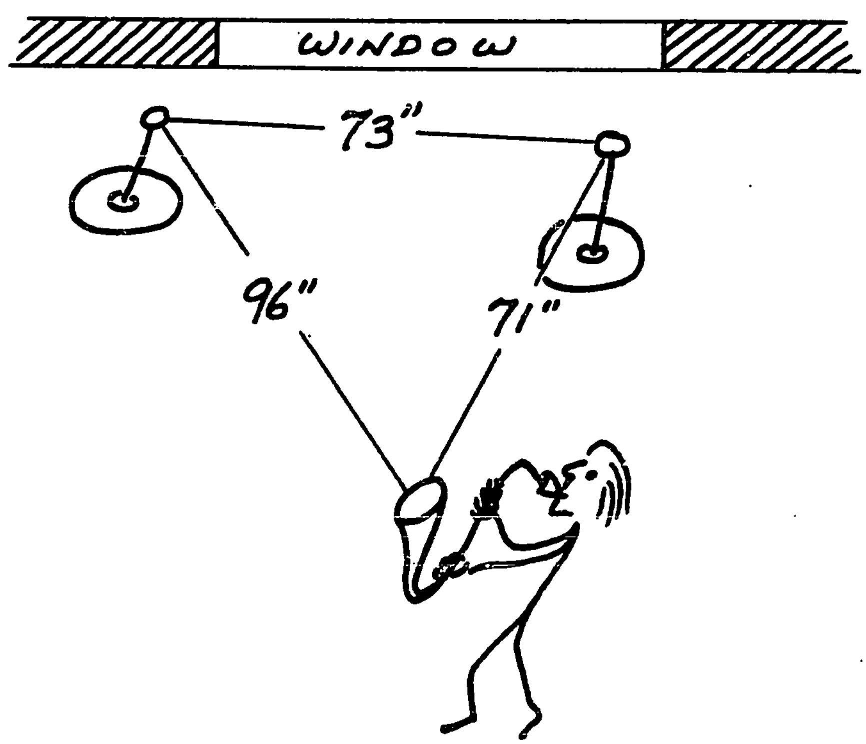
Test 6

To aid in a study of the effect of "lipping-down" on tone quality, the two tones most often requiring considerable lowering in pitch (d^2 and a^2) were recorded from mouthpiece A at "natural" and "in-tune" versions.

All of the recording for Tests 4, 5 and 6 was done in the Radio Studio on the campus of the State

University College at Fredonia. The studio itself is a moderately "dead" room with draperies around three of the four walls. In order to minimize the possibility of interference effects caused by possible superposition of reflected sound waves in the room, two microphones were used, each at a slightly different distance from the instrument. The exact placement was determined by listening to the instrument through the microphones and moving them about the room until a "real" sound was heard. The placement of the microphones relative to the performer is shown in Fig. 28.

Fig. 28. Microphone Placement.



The performer was situated about eight feet from a glass studio window through which he could see a Stroboconn tuning instrument. Each of the test tones produced for recording could thus be played in tune. It was felt that these "in-tune" tones would be most like tones in a musical context in regard to their quality. The tones were all played using vibrato so that they would be as relaxed and natural as possible. All tones were played at a <u>mf</u> dynamic level as judged by the performer. Some acoustical studies, which make use of recorded tones, have the player watch a sound level meter and make all of the tones the same in sound pressure level. There are great differences between the psychological feelings of loudness and sound pressure levels. Playing from one register on the instrument to another with equal dynamic level shows significant difference in sound pressure level. The use of a constant <u>mf</u> level was felt by the author to be more representative of the true musical situation. The microphones (two U-67 Neuman microphones) were situated at a height of forty-eight inches from the floor. The performer stood for the playing of the tones. An Ampex model 351 tape recorder was used for making the recordings on Scotch 120 tape (tape speed--15 ips). The recordings of the tones produced by the basic twelve mouthpieces were all conducted on the same day. The same procedures in regard to reed and its placement were used as those outlined in the instructions for the subjective testing. A tone of approximately eight seconds duration was recorded for each pitch used in the testing.

Test 7

The preparation of recorded test tones for spectrum analysis had to be done also for four other mouthpieces (W, X, Y, and Z). For these the procedure was a bit more complicated. Each of these mouthpieces was to undergo a series of modifications in a single factor of design in order to further isolate that factor's contribution to tone quality and playing characteristics. Mouthpiece W was to be used for a study of end-wall shape, mouthpiece X for a study of the bore-to-table angle, mouthpiece Y for a study of beak shape (the outside shape at the tip end of the mouthpiece) and window length, and mouthpiece Z for a study of air turbulence within the chamber. Not only were recorded tones required, but Stroboconn intonation tests and subjective tests had to be made at the same time, since by the nature of the changes occurring in a single mouthpiece, one could not return to the original form of the mouthpiece to carry out these other tests at a later time. All modifications in the chamber had to be carried out at the recording studio. After each modification, the performer and a saxophone player assistant made separate subjective judgments on the tone quality and playing characteristics from the vantage points of player and listener. Then recordings were made using the six tones of Fig. 27. At the time of the recording process, the assistant ran Stroboconn intonation tests on those six tones. In these tests it was not possible for the player to observe the Stroboconn tuner during recording as had been the case with the recordings of the basic twelve test mouthpieces.

A Fourier spectrum analysis was made of each of the tones recorded on tape. A simple steady-state analysis was judged as adequate for the comparison to be made. The recorded tones were played back on a Sony model 600 tape recorder which was connected directly to a Systron Donner model 710 spectrum analyzer display unit. This analyzer displayed the analysis on an oscilliscope tube. A Hewlett-Packard model 7035B X-Y Recorder was connected to the analyzer for making permanent inked graphs of the analysis of each tone. These graphs were translated into bar graphs of the relative strengths of the various harmonic components of each tone. The bar graphs representing the spectrum analysis of the twelve test mouthpieces plus the modification tests of mouthpieces *W*, *X*, *Y*, and *Z* are to be found in Appendix C (p. 138). Instructions for the proper interpretation of the graphs may be found on the first page of this appendix.

Test 8

An additional test was carried out to determine the "carrying power" of mouthpieces *A*, *B*, *C*, *D*, and *E*. It took place in an open field about 350 by 450 feet. The saxophone, played by the author, and the measuring instruments were at all times a minimum of 150 feet from the nearest trees or buildings. Three test tones were used: b^{b}, b^{b1}, and b^{b2} representing tones from the low, middle, and high registers of the alto saxophone. A sound level meter at the location of the saxophone enabled the player to maintain a constant sound pressure level of 80 dB on all test tones. Readings of the sound level (using A-scale weighting)[7] at straight

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[7]Since loudness is dependent upon frequency as well as sound-pressure, it is customary for sound-level meters to be equipped with three weighting networks designated as A, B, and C. These networks are based upon equal-loudness contours developed by Fletcher and Munson. The A-scale weighting indicated here is that normally used when measuring levels below 55 dB. It is based upon the 40-phon Fletcher-Munson contour. The weighting network used must be stated in connection with sound-level readings.

line distances of 25, 50, 75, and 100 feet directly in front of the player were made using a General Radio sound level meter (Type 1551-C) to determine the relative drop-off of sound level between the different mouthpiece designs at different distances from the instrument. The ambient noise level (background noise caused by wind, etc.) varied between 40-43 dB during the tests. Background noise corrections were made for all sound-level measurements.

The findings of all of the experiments and tests discussed in this chapter are reported in detail in Chapters III, IV, and V. Technical descriptions and specifications of the equipment used in recording, spectrum analysis, and measurement of frequency and sound level are found in Appendix D (p. 162). Temperature, air pressure, and humidity readings taken at the time of testing are found in Appendix E (p. 179).

CHAPTER III

INFLUENCE OF MOUTHPIECE DESIGN ON TONE QUALITY

Preliminary Considerations

In examining the harmonic spectrum graphs found in Appendix C (p. 138), one must keep in mind that there are certain influences on tone quality which are not related directly to mouthpiece design. First and foremost of these is the player's own concept of saxophone tone. The tone quality of a player is not independent of the influence of past listening to saxophone tone and the direction given by his mind to produce this or that type of saxophone tone. Regardless of the mouthpiece used, a player's concept of what he thinks a saxophone should sound like will be an influence. The selection of a mouthpiece which has a chamber design which will give a tone quality close to that of the player's "ideal" is important. Otherwise, the player will have to fight the mouthpiece tendencies by the use of extreme facings, reed contours and the like. Other influences of the player on the tone produced can be traced to differences between individuals in the shape and size of their oral and sinus cavities. Although acoustical studies have shown that oral cavity shape and size have no effect upon tone quality,[1] many musicians still feel that the oral cavity has much to do with the "centering" of a tone and with making various adjustments in the pitch of a tone. The oral cavity also is an important aid in the damping necessary when playing in the second mode of vibration.

Another influence upon tone quality which must be kept in mind as one examines the spectrum graphs is that of "lipping down." This is probably a misleading term to use in describing the lowering of a pitch through the use of a combination or oral cavity shape and slight changes in embouchure, but it is the term generally used by musicians. Because it is impractical to build a saxophone which plays perfectly in tune, some adjustment on the part of the player must be made to assure correct intonation. Certain tones need to be adjusted more than others. For instance, the two pitches $\underline{d}^2$ and $\underline{a}^2$, are generally quite sharp and must be brought down in pitch considerably. In an effort to observe the change in tone quality brought

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[1]Sam E. Parker, "Analyses of the Tones of Wooden and Metal Clarinets," Journal of the Acoustical Society of America, XIX (May, 1947), 417.

about through this "lipping down" process, test tones were analyzed of these two pitches in their "normal" and "lipped down" states (Test 6, p. 54). Figs. 29 and 30 show the results of this test in spectrum graph form.[2] The results are more obvious for pitch $\underline{a}^2$ where there is a strengthening of partials 1 and 2 and a weakening of all the higher ones. For $\underline{d}^2$, partials 1 and 3 are weakened and 2 and 4 are strengthened along with a general strengthening and smoothing out of the drop-off in energy level for partials 5 and higher. The "lipped down" tones are judged to be "darker" in quality.

A common fault among students is the incorrect positioning of the mouthpiece on the neck cork. When this is the case, the mouthpiece is usually not positioned far enough on the neck with the result that the embouchure must be overly tight and the general focus very high to bring the tone up to the correct pitch. This has the effect of adding extra brightness and "edge" to the tone. Another fault which affects tone quality is that of pinching when playing very softly. In addition to tending to raise the pitch, this also has a brightening effect

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[2]In Figs. 29 through 35 the base line represents a sound pressure level of zero dB. The other horizontal lines represent 20 dB, 40 dB, and 60 dB. The numbers beneath the base line identify the various harmonics.

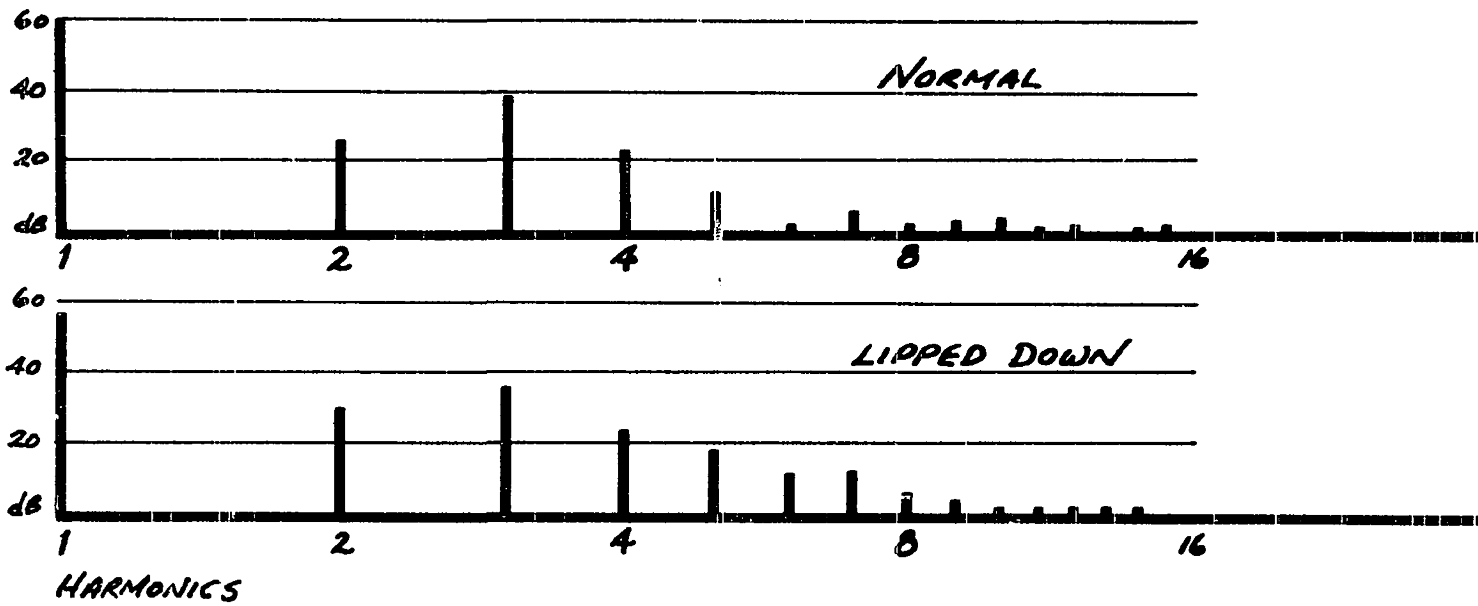

Fig. 29. Effect of Pitch Adjustment for $\underline{d}^2$.

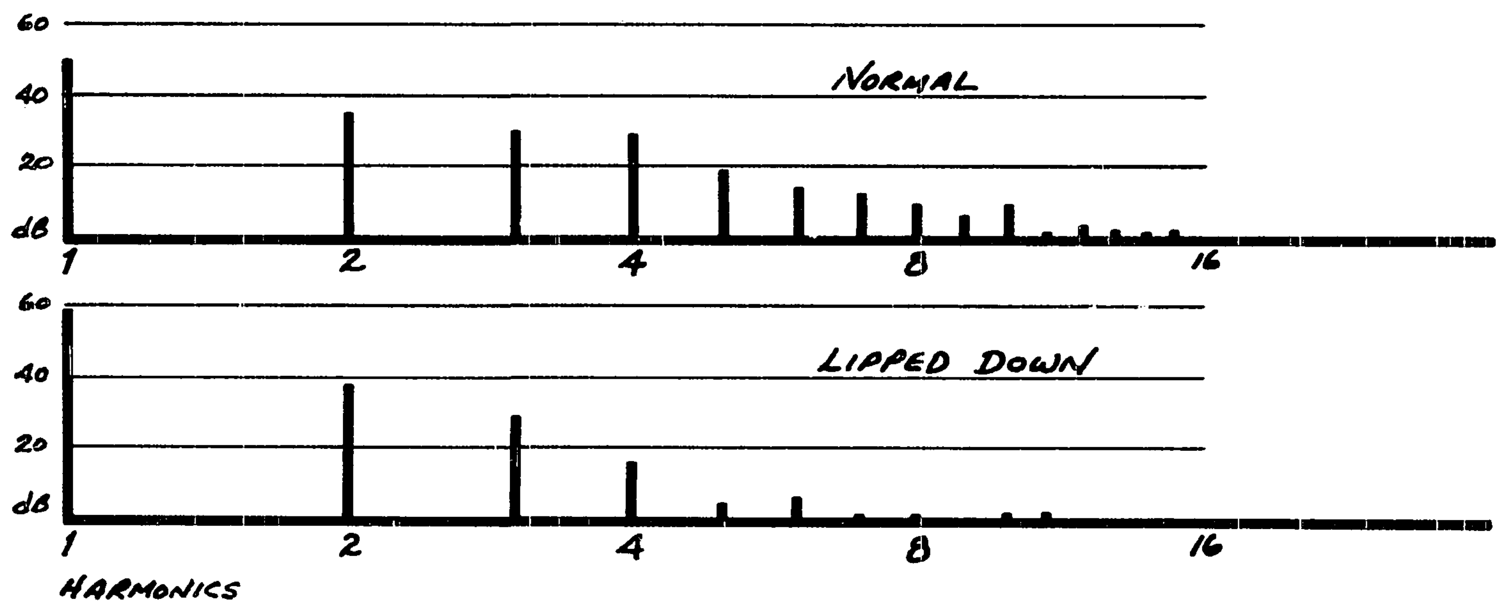

Fig. 30. Effect of Pitch Adjustment for $\underline{a}^2$.

on the tone.

Dynamic level also affects tone quality. A test was made (Test 5, p. 54) using the five basic mouthpiece types (A, B, C, D, and E) to determine if the mouthpiece design made any difference in the relationship between dynamic level and tone quality. The pitch f^2 was used as the test tone. Spectrum graphs for this test are shown in Figs. 31 through 35. For all mouthpieces, an increase in dynamic level resulted in an increase in the number and intensities of upper partials. Between mf and ff the trend was for partials 2 and 4 to decrease while partials 1, 3, 5, 7, and all higher partials increased. Mouthpiece B did not conform to the general pattern in that partial 2 increased and 3 was weakened. The increase in the number of partials present as the dynamic level increased was quite uniform for mouthpieces A and E. Mouthpieces B, C, and D showed greater increase between pp and mf than between mf and ff. This caused an uneven increase in the brightness of the tone for equal increases in dynamic level. There was much less difference in spectrum shape for all mouthpieces at the pp level, although D extended the predominance of partial 3 over partial 2 even down to the pp level.

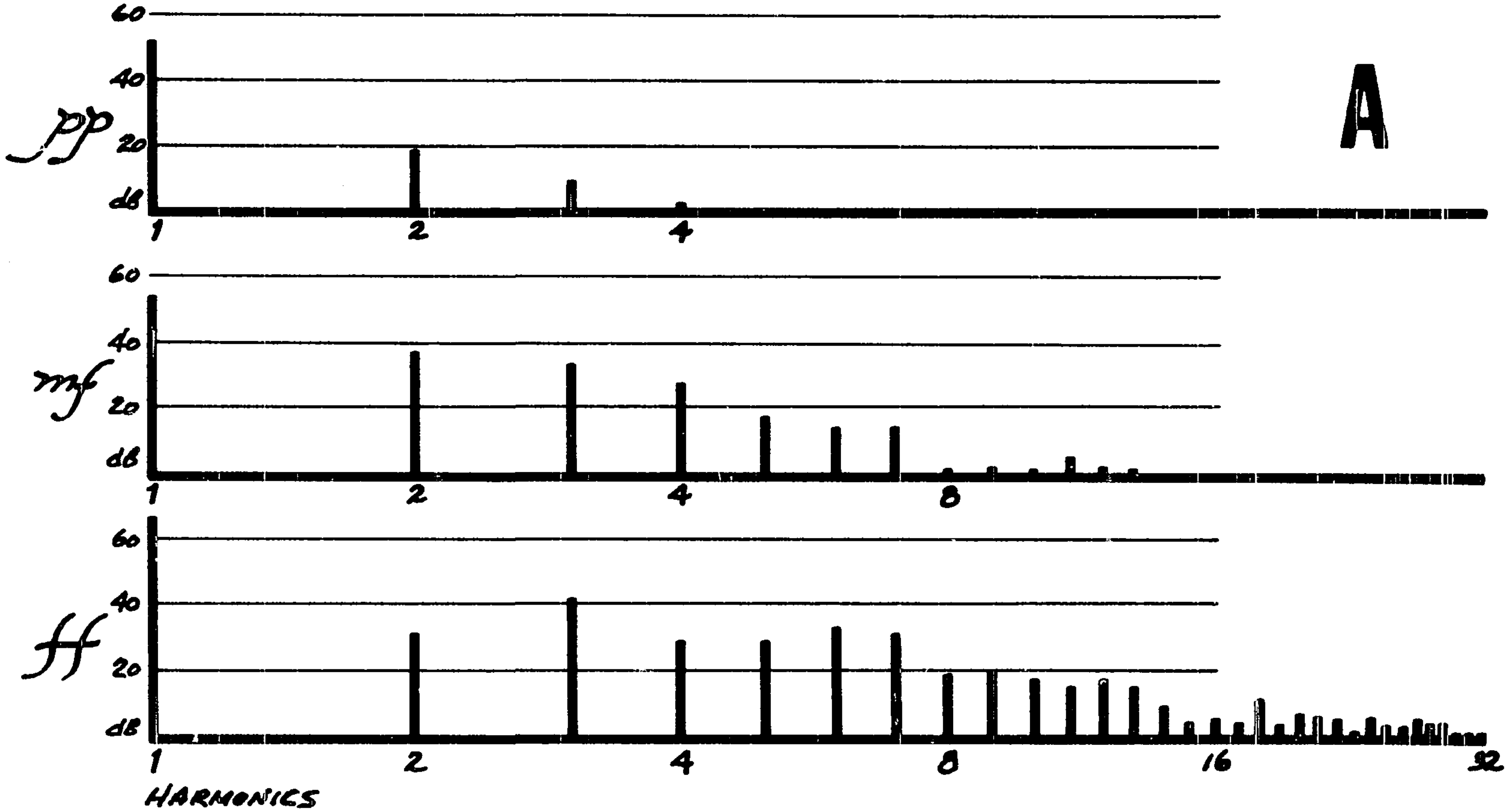

Fig. 31. Effect of Dynamic Change for Mouthpiece A.

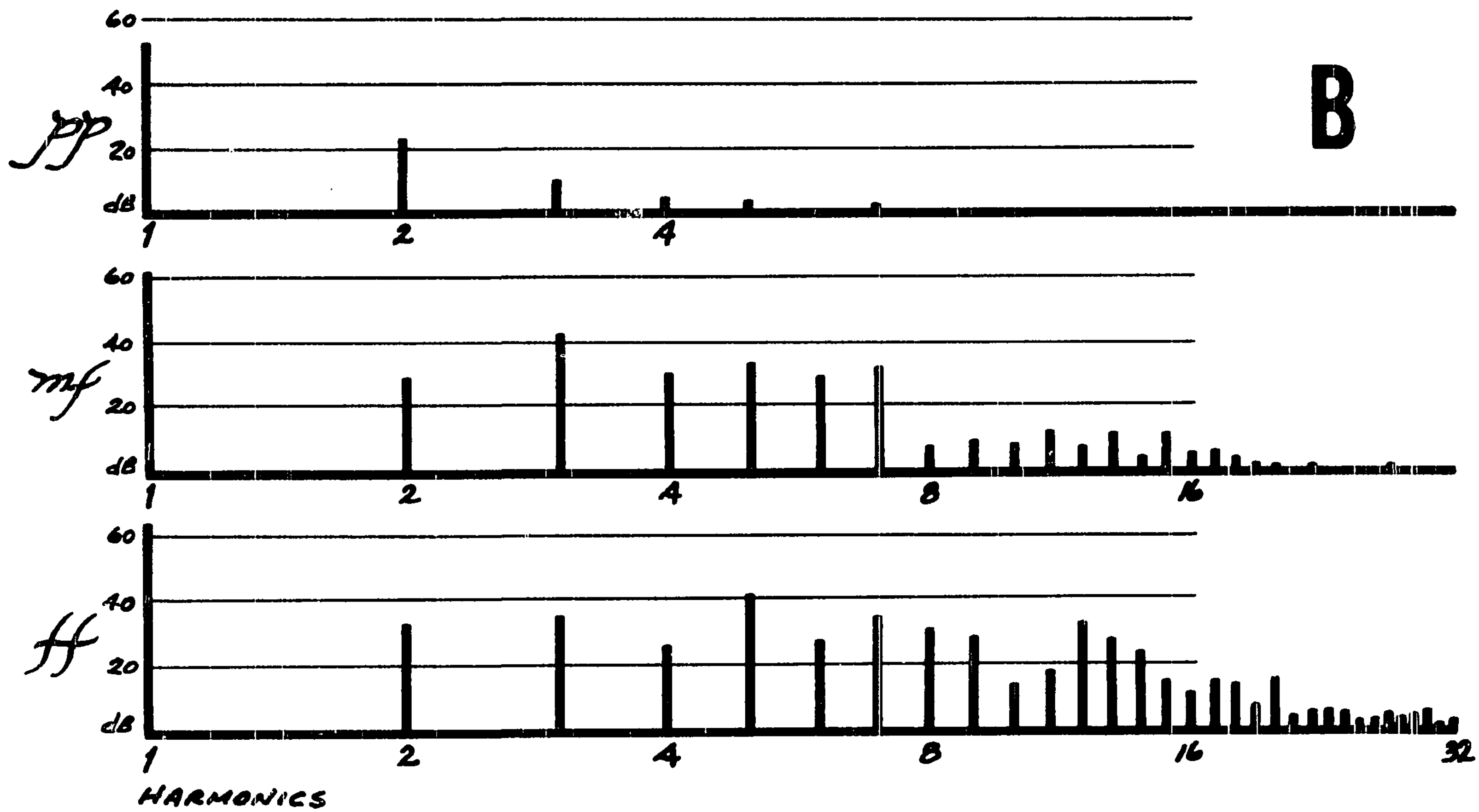

Fig. 32. Effect of Dynamic Change for Mouthpiece B.

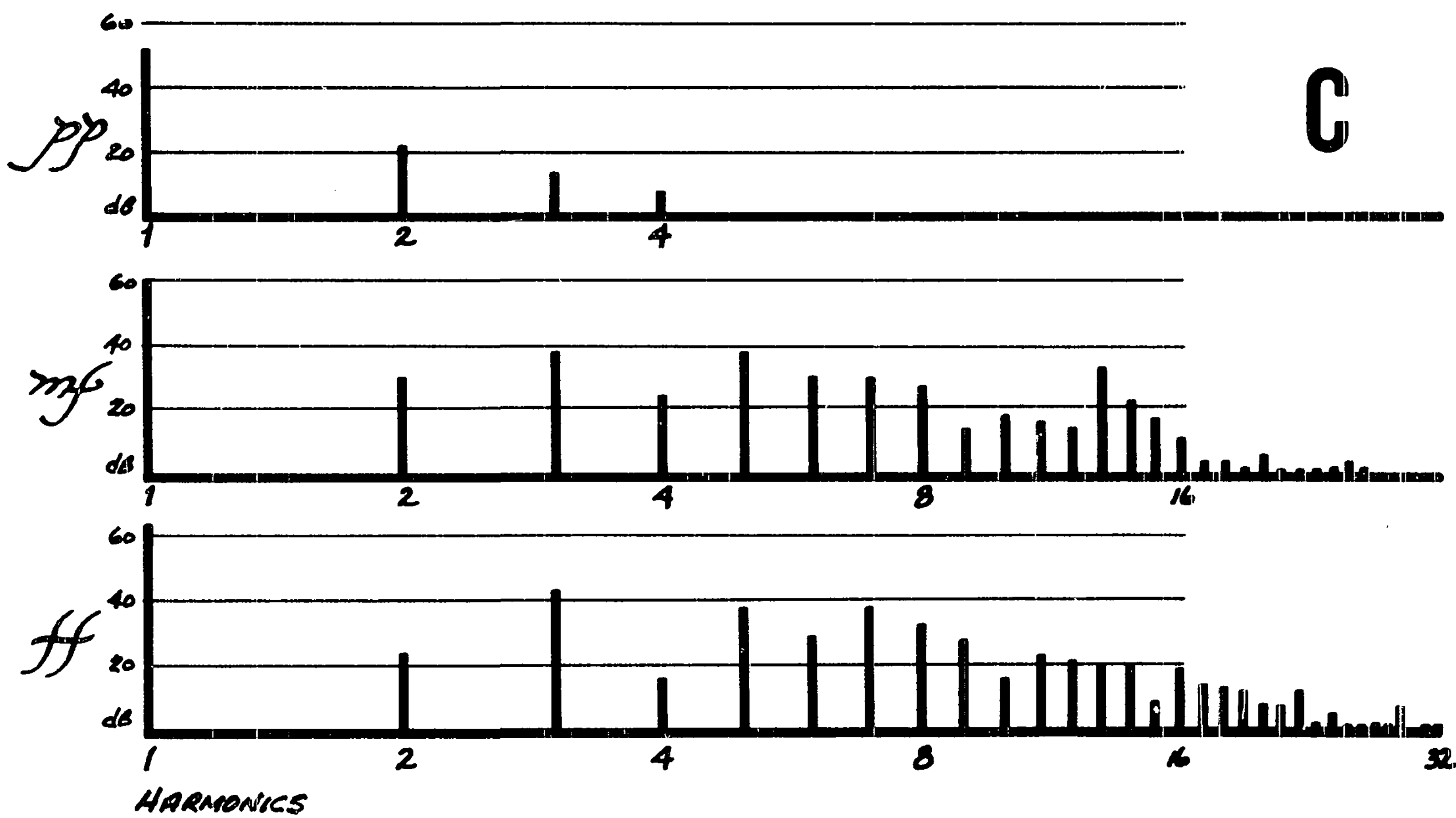

Fig. 33. Effect of Dynamic Change for Mouthpiece C.

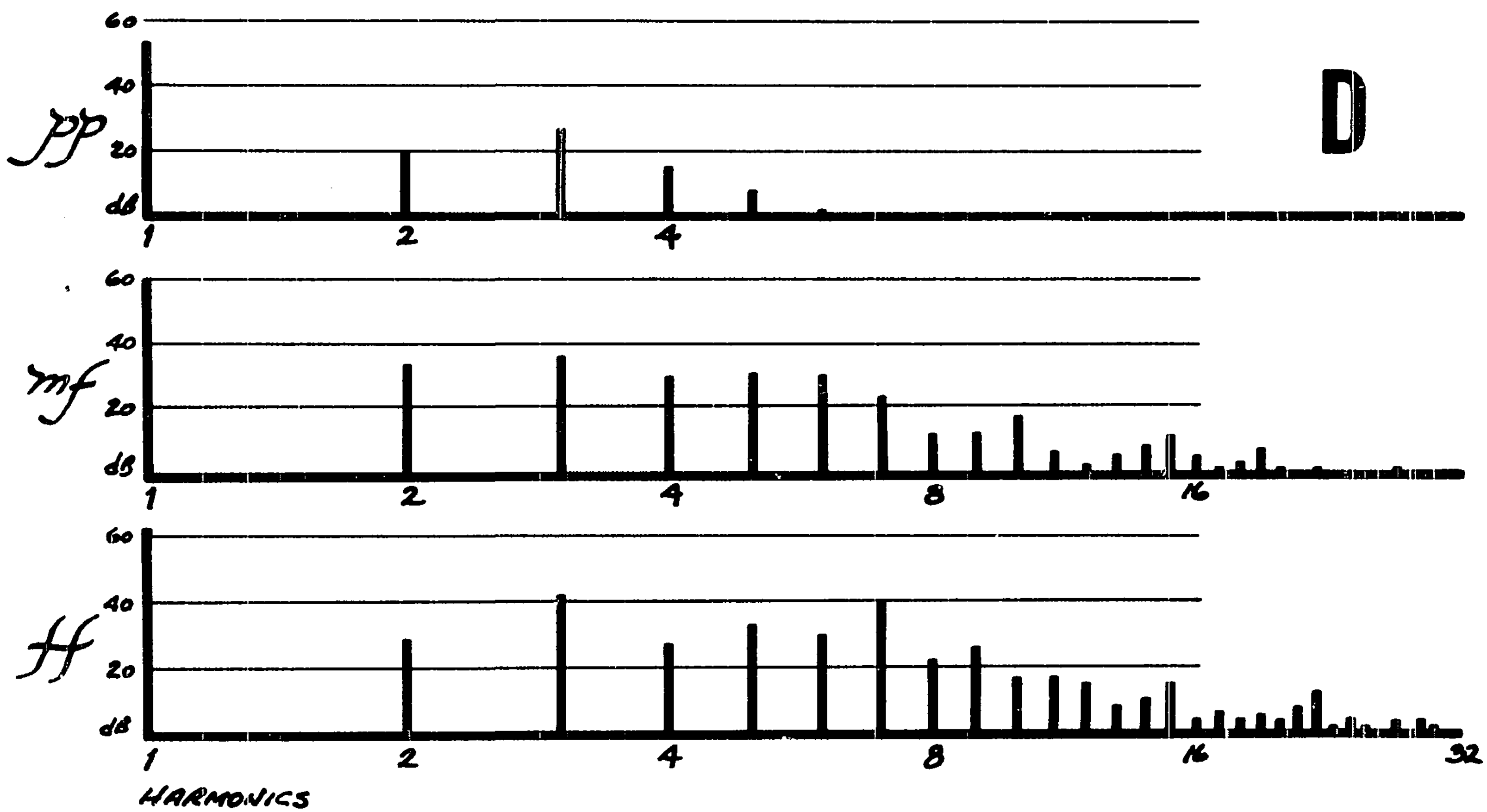

Fig. 34. Effect of Dynamic Change for Mouthpiece D.

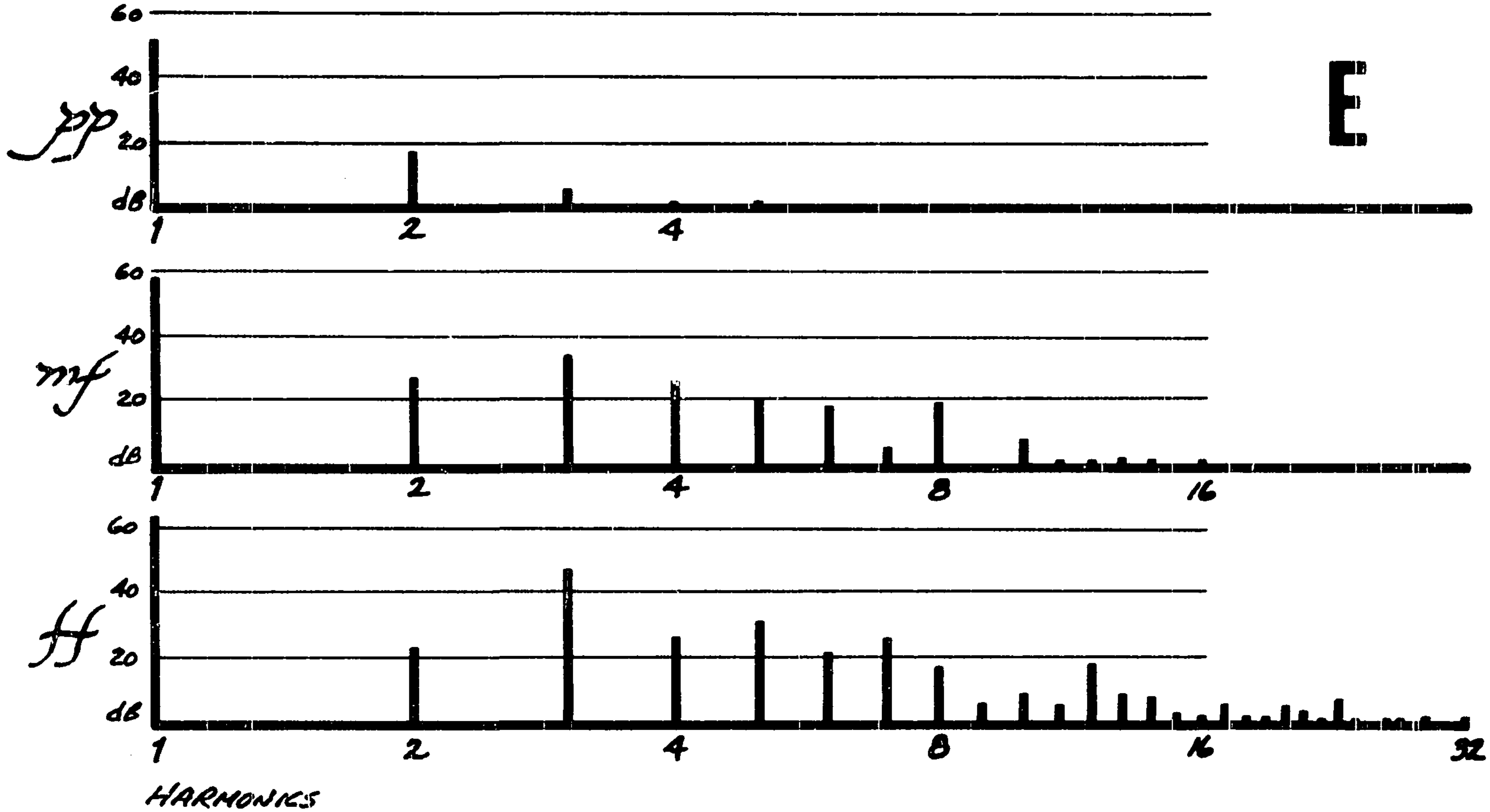

Fig. 35. Effect of Dynamic Change for Mouthpiece E.

Brightness

The relationship between the subjective terms used to describe tone and the spectrum analysis of the test mouthpieces should perhaps be described (Test 1, p. 50). The ranking of the five basic mouthpieces as to brightness of tone quality was called for in the subjective testing (Appendix B, p. 134). Table 3 shows the answers as given by the eight subjects.

Table 3. Relative Brightness of Test Mouthpieces.

Subject	dark-mellow ⟷ edgy-bright
1	E A D B C
2	A E C B D
3	A E B D C
4	A E B D C
5	A E C D B
6	A E D C B
7	E A D C B
8	A E C D B

There was general agreement with one exception that A was the darkest mouthpiece and that E was the next darkest. There was some difference of opinion as to how B, C, and D were ranked towards the bright end of the continuum.

The author ranked all twelve of the test mouthpieces in the following order, beginning with the darkest and proceeding to the brightest:

A, E, D-1, B-1, A-1, C-2, C, A-2, B, B-2, D, C-1

Alexander Wood had established that the saxophone tone has a strong fundamental and relatively even distribution of energy in the partials up to around fifteen.[3] The following general description of tone and its harmonic content by Alexander Wood was helpful as a basis for comparison between mouthpieces.[4]

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[3]Alexander Wood, The Physics of Music, ed. J. M. Bowsher (6th ed.; London: Methuen, 1962), p. 72.

[4]Ibid., pp. 70-71.

Energy in only lowest partials (pure tone)	-	soft, pleasant, no roughness, wanting in power, dull in lower pitches
Moderate energy in first six partials	-	more harmonious and musical, rich and splendid, sweet and soft if higher partials are absent
Prominent energy in partials above sixth	-	cutting and even rough, reedy

Burnau stated that the fourth partial was next in strength after the fundamental.[5] The author found this to be the case in only a few isolated cases and then only at the top-most notes of the fundamental mode of vibration ($c^{\#2}$). Partial 2 or 3 was usually next in strength to that of the fundamental.

Benade showed the saxophone to be much more consistent in spectrum shape between different registers than the clarinet.[6] Patrick pointed out the balanced overtone spectrum of the mouthpiece with an excavated chamber and the "harsh and strident" quality of the small or narrow chamber.[7]

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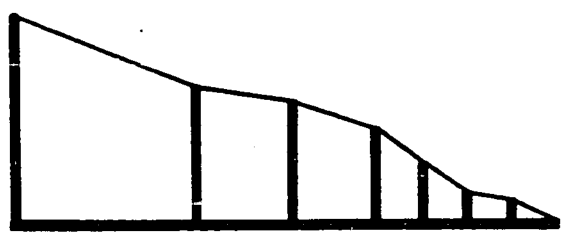
[5]John Burnau, "Adolphe Sax - Inventor, the Saxophone Family," Instrumentalist, XXI (January, 1967), 42.

[6]Arthur Benade, Horns, Strings and Harmony (New York: Doubleday and Co., 1960), p. 231.

[7]Lee Patrick, op. cit., p. 74.

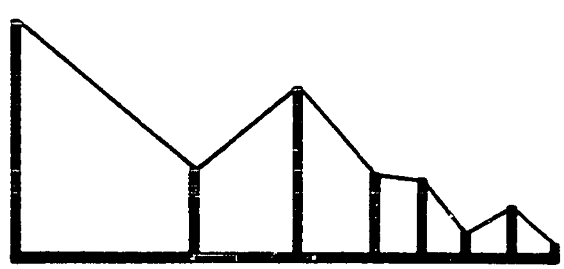
All performers taking part in the testing agreed that mouthpiece A was the darkest in tone quality. For this mouthpiece, energy was distributed over only a small number of harmonics. This mouthpiece was most consistent in exhibiting a spectrum shape in which the harmonics progressively decrease in strength from the strong fundamental as shown in Fig. 36.

Fig. 36. General Spectrum for Mouthpiece A.



As the saxophone tone became a bit richer in quality, as can be seen in A-1, energy was found in slightly higher partials. As this happened, a corresponding decrease occurred in partials 2 and 4 giving rise to structures with the configuration of Fig. 37.

Fig. 37. General Spectrum for Mouthpiece A-1.



The brighter a mouthpiece becomes, the less it tends to show a smooth decrease in partial strength for the higher harmonics. Brightness does not seem to depend on the total number of harmonics in a tone, but upon the amounts of energy above certain fixed frequency points. For the tones analyzed in the spectrum graphs of Appendix C (p. 138), one can observe this easily. The relative brightness of mouthpieces correlates well with the amount of energy found above 1600 Hertz, regardless of the location of the fundamental frequency. As the energy above this frequency increases, the subjective feeling is described as added brilliance. When significant amounts begin to show above 3200 Hertz, the quality begins to be described as "edgy." At higher dynamic levels than the *mf* used for these test tones, the ear seems to allow for an increase in harmonic energy all of the way up to 12,800 Hertz without a feeling of excessive brilliance or "edge." At the *mf* level little energy is found above 6400 Hertz for any of the mouthpieces, no matter how bright they may be. Previous studies by Risset and Mathews have shown that frequencies above 4000 Hertz may add to the brilliance of a tone, but that they do not contribute much to the recognition of what instrument is playing.[8]

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[8]Jean-Claude Risset and Max V. Mathews, "Analysis of Musical-Instrument Tones," *Physics Today*, XXII (February, 1969), 26.

In a spectrum analysis of woodwind instruments, Benade came to the conclusion that the strength of only the lower partials of a woodwind instrument tone is determined by the shape of the bore of the instrument and the mouthpiece. According to Benade, the strength of the upper partials is determined by the reed and player.[9] The present investigation has produced results sharply at odds with Benade's conclusion since mouthpiece design is shown to be a large factor in the number and strengths of the upper harmonics.

Evenness Throughout Range

The subjective testing required a comparison of the test mouthpieces with regard to their effect on the evenness of tone quality throughout the range of the instrument. This was to include a comparison of the change of quality which occurs when moving between different registers. The tone $\underline{c}^{\#2}$ and all pitches below it are normally played in the fundamental mode of vibration. These pitches make up the low register. Above $\underline{c}^{\#2}$, referred to as the second register, pitches must be played as "overblown" harmonics of the lower register tones. The

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[9]Arthur Benade, "On the Tone Color of Wind Instruments," Selmer Bandwagon, No. 59 (1970), p. 21.

change of quality which occurs between the highest tone of the low register and the lowest tone of the second register is referred to as a "break." This is the "$\underline{c}^{\#2}$-$\underline{d}^{2}$ break." A minor "break" also occurs at the point in the second register where the change of vent holes occurs (between $\underline{g}^{\#2}$ and $\underline{a}^{2}$). Players ranked the five test mouthpieces on evenness of tone quality as follows in Table 4.

Table 4. Evenness of Scale of Test Mouthpieces.

Subject	most even				least even
1	E	A	D	B	C
2	E	A	C	D	B
3	A	E	D	B	C
4	A	E	D	B	C
5	E	C	B	D	A
6	A	E	C	D	B
7	E	A	D	C	B
8	A	E	C	D	B

The author judged the twelve test mouthpieces to be in the following order from the most even to the least:

A, A-1, E, C-2, D-1, A-2, B-1, B-2, B, C-1, C, D

Evenness of tone quality throughout the range was found to depend upon the combined effect of two factors: (1) the uniformity of the spectral shape and (2) the uniformity of brightness in the tone. Spectral shapes were derived from the spectrum graphs of Appendix C by connecting with lines the tops of the vertical bars representing the strength of individual harmonics. By superimposing the spectral shapes of the test tones $\underline{b}^b$, $\underline{f}^1$, $\underline{c}^{\#2}$, $\underline{d}^2$, $\underline{f}^2$, and $\underline{c}^{\#3}$ for each of the twelve test mouthpieces, it was possible to study the consistency of shape among these test tones. These sets of superimposed spectral shapes for the test mouthpieces are shown in Fig. 38.

The uniformity of brightness of tones throughout the range of the saxophone can be seen by noting the amounts of energy above 3200 Hertz for each test tone. An examination of the spectrum graphs found in Appendix C (p. 138) will reveal this. Figure 39 shows the graph for mouthpiece C, an example of a mouthpiece with an uneven brightness factor. Notice the weakness in energy for $\underline{f}^1$, $\underline{d}^2$, and $\underline{a}^2$. On the other hand, mouthpiece A, seen in Fig. 40, consistently has negligible amounts of energy above 3200 Hertz until the highest test tones.

Fig. 38. Spectral Shapes.

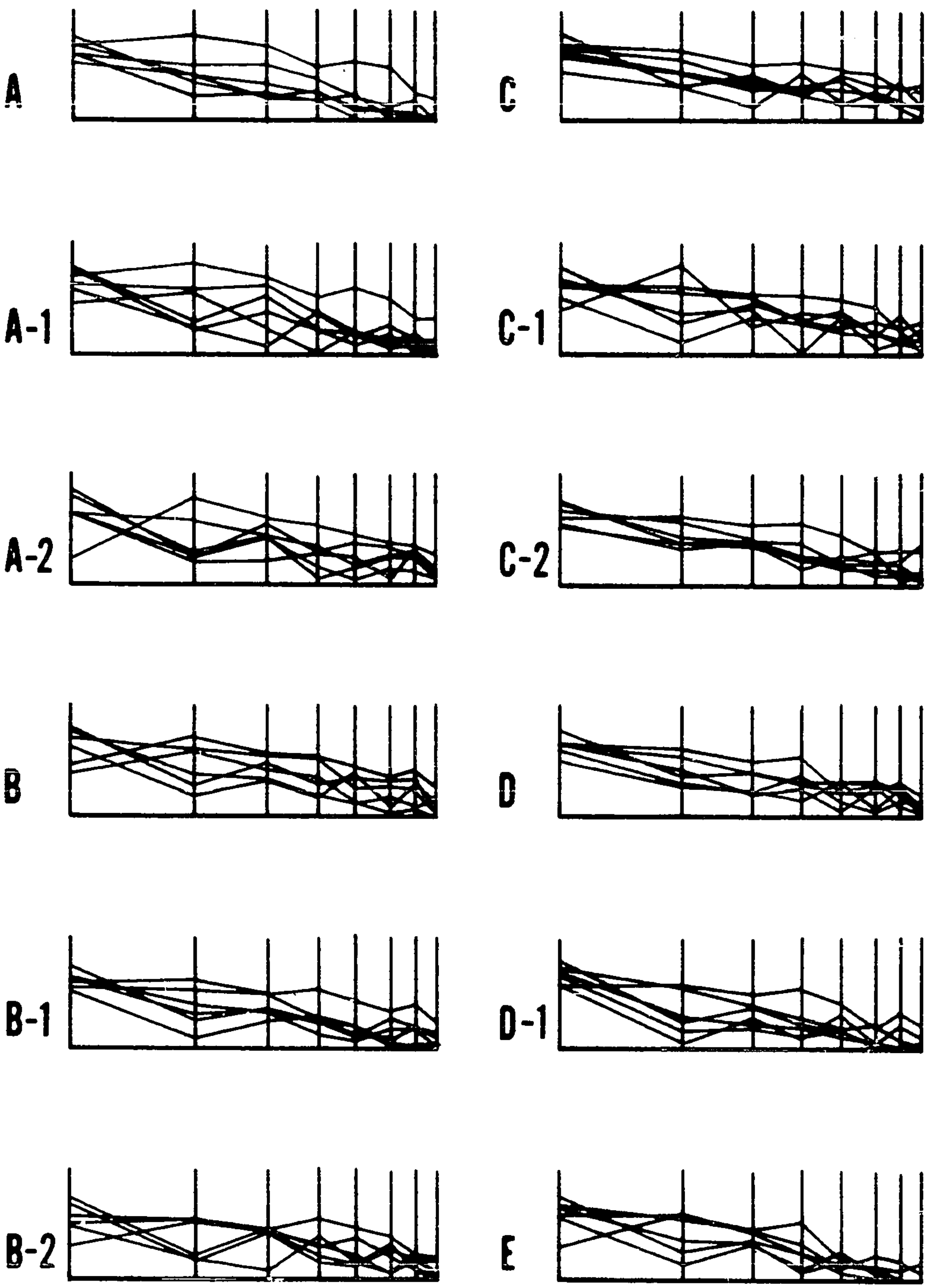


Fig. 39. Brightness: Mouthpiece C.

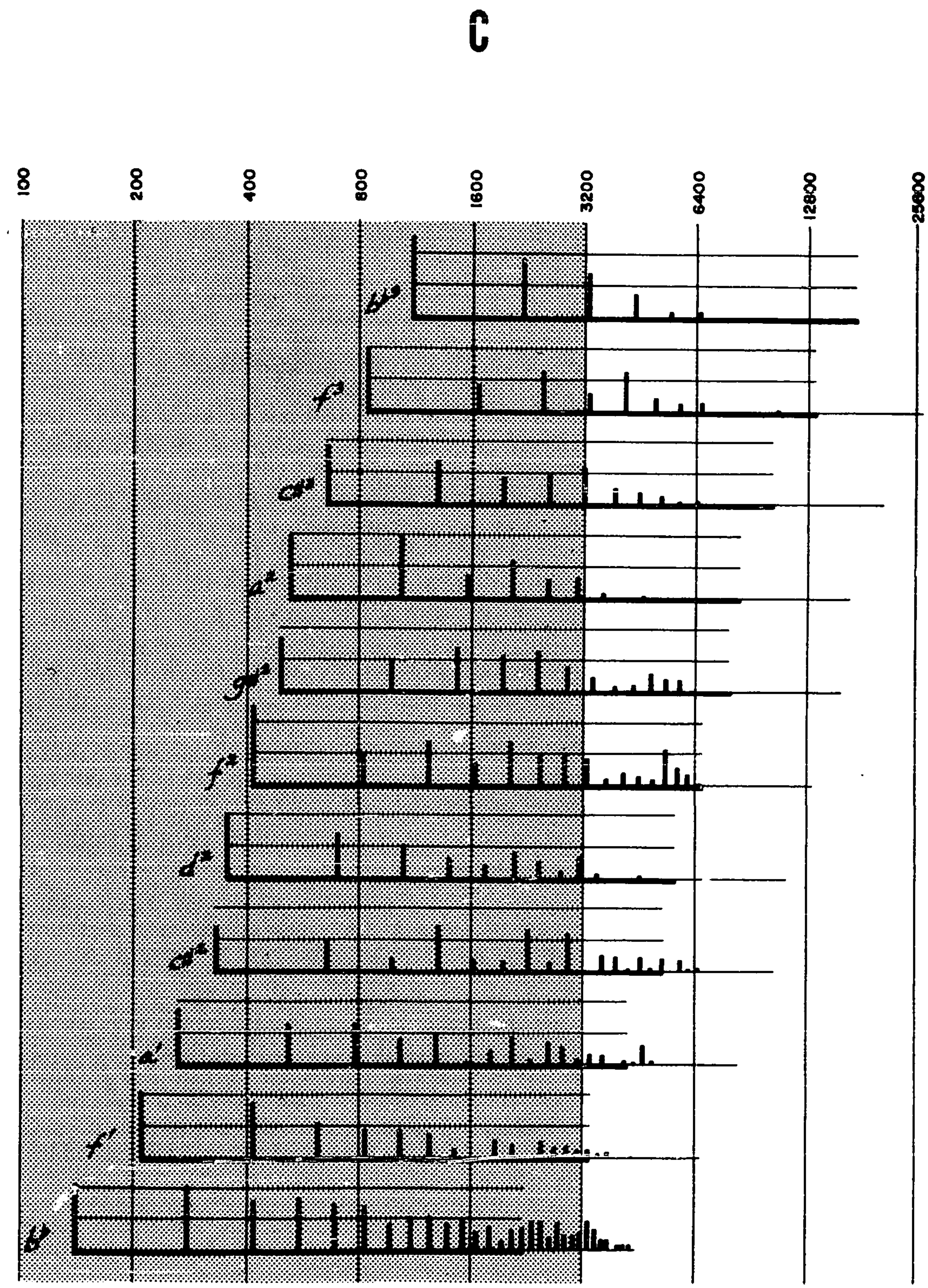
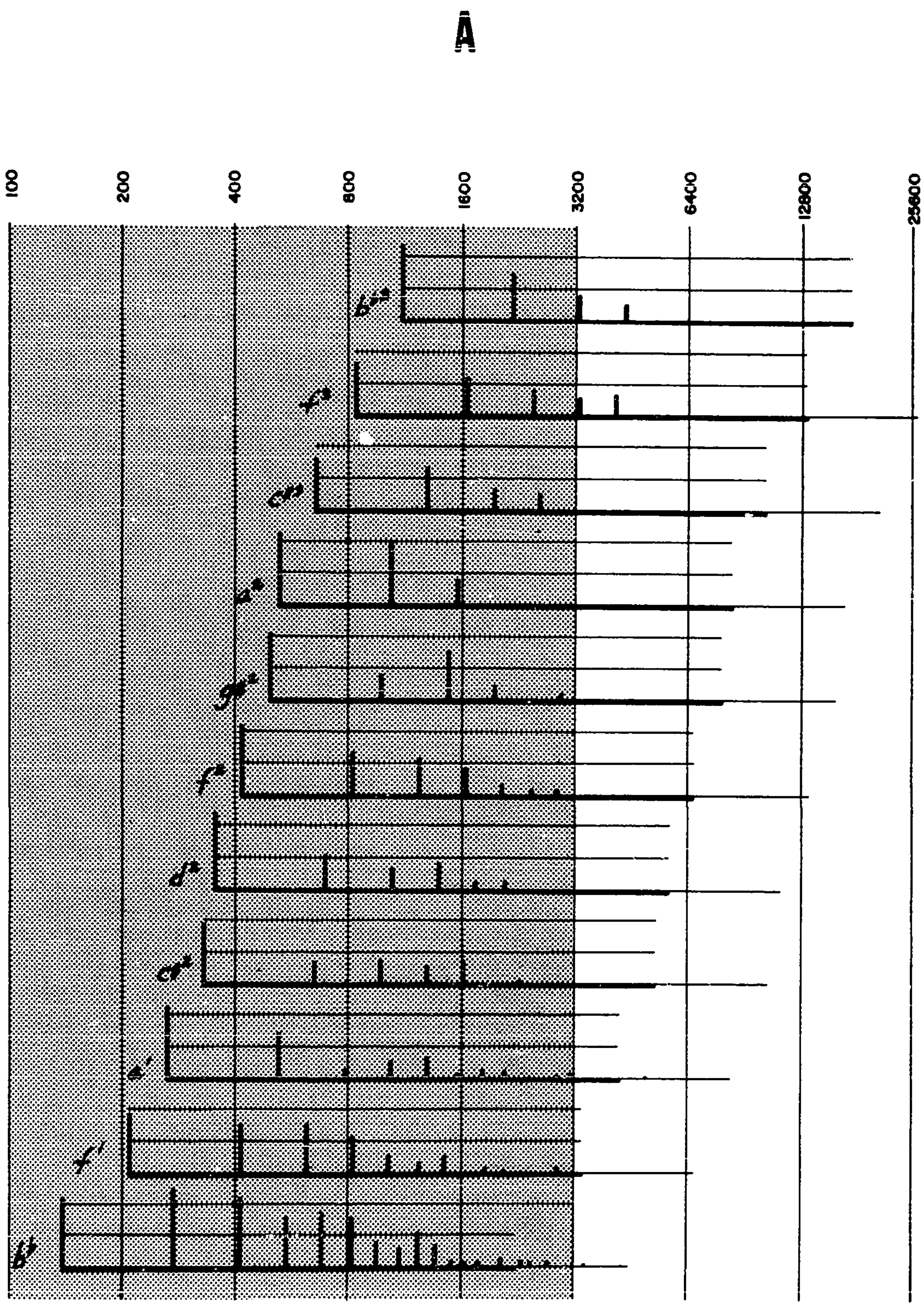


Fig. 40. Brightness: Mouthpiece A.



Undamped and Sympathetic Partials

The investigation of the spectrum graphs for possible evidence of formant regions disclosed no evidence of strong zones of reinforcement. Much more interesting, however, was a significant occurance of inharmonic partials. Rather than being random and unexplainable as to their cause, these partials were observed to come from two sources. The first source is observed in the structure of pitches in the second mode of vibration (overblown at the octave). The fundamental for the length of tube being used is actually an octave below the heard fundamental for the pitch being played. The odd-numbered partials are for the most part damped out when one plays in the second mode of vibration. However, these partials of the first or fundamental mode of vibration are not always completely damped (damping is usually done by correct focus of the player and by the aid of venting holes) and they appear as extra partials between the components of the tone in the second register.

The second source of inharmonic partials is, surprisingly, the fundamental tube length of the entire instrument. It seems that the common view that the length of tube extending past the last open hole of a given fingering has little effect upon the tone needs some modification. The energy in these inharmonic partials is over 10 dB in some instances. In these amounts, they must have some effect on tone quality. In the fundamental mode of vibration, they begin to be observable only in the highest tone of that mode ($\underline{c}^{\#2}$). The influence on these notes is only from the lowest fundamental series of the instrument. In the second register ($\underline{d}^2$ up to $\underline{f}^3$) the inharmonic partials become more significant as one goes higher in the register. The low portion of the second register seems to have its extra partials derived from undamped partials of the fundamental mode of vibration of the used tube length. As one ascends above $\underline{f}^2$, the influence of the low $\underline{b}^b$ series becomes greater until in the tone of $\underline{b}^{b3}$ it is exceptionally strong. These inharmonic partials, even when over 10 dB in strength, have been omitted from the spectrum graphs of Appendix C in order to avoid confusion for the reader.

The inharmonic partials which come from the fundamental series of the total instrument are most pronounced and uniform when the note being sounded is part of that harmonic series. Only three of the pitches in that series were among the test tones recorded for this study, but further study should reveal that all tones belonging to the fundamental series of an instrument would have a sympathetic reinforcement from this source of inharmonic partials, while the tones falling between them would not have this reinforcement. A certain subtle tonal tension may exist within the scale of all woodwind instruments as a result of the influence of the fundamental series of the instrument. The selection by some of $\underline{f}^2$ as a more satisfactory tuning note, for the saxophone, than the usual $\underline{f}^{\#2}$ may be explained by this phenomenon.

Inharmonic partials are generally stronger when mouthpiece resistance is high. From $\underline{g}^{\#2}$ upward there is more strength in these partials for brighter mouthpieces, but the brighter the mouthpiece, the more irregular and displaced in pitch they seem to be. For the tone $\underline{b}^{b3}$, mouthpieces A and E are most uniform and have little displacement. Two illustrations showing the undamped and sympathetic partial phenomenon are shown in spectrum graph form in Fig. 41.

Specific Design Parameters

A detailed account of the effects of the various design characteristics upon tone quality will now be given. The exact measurements for each of the test mouthpieces are found in Appendix A (p. 127).

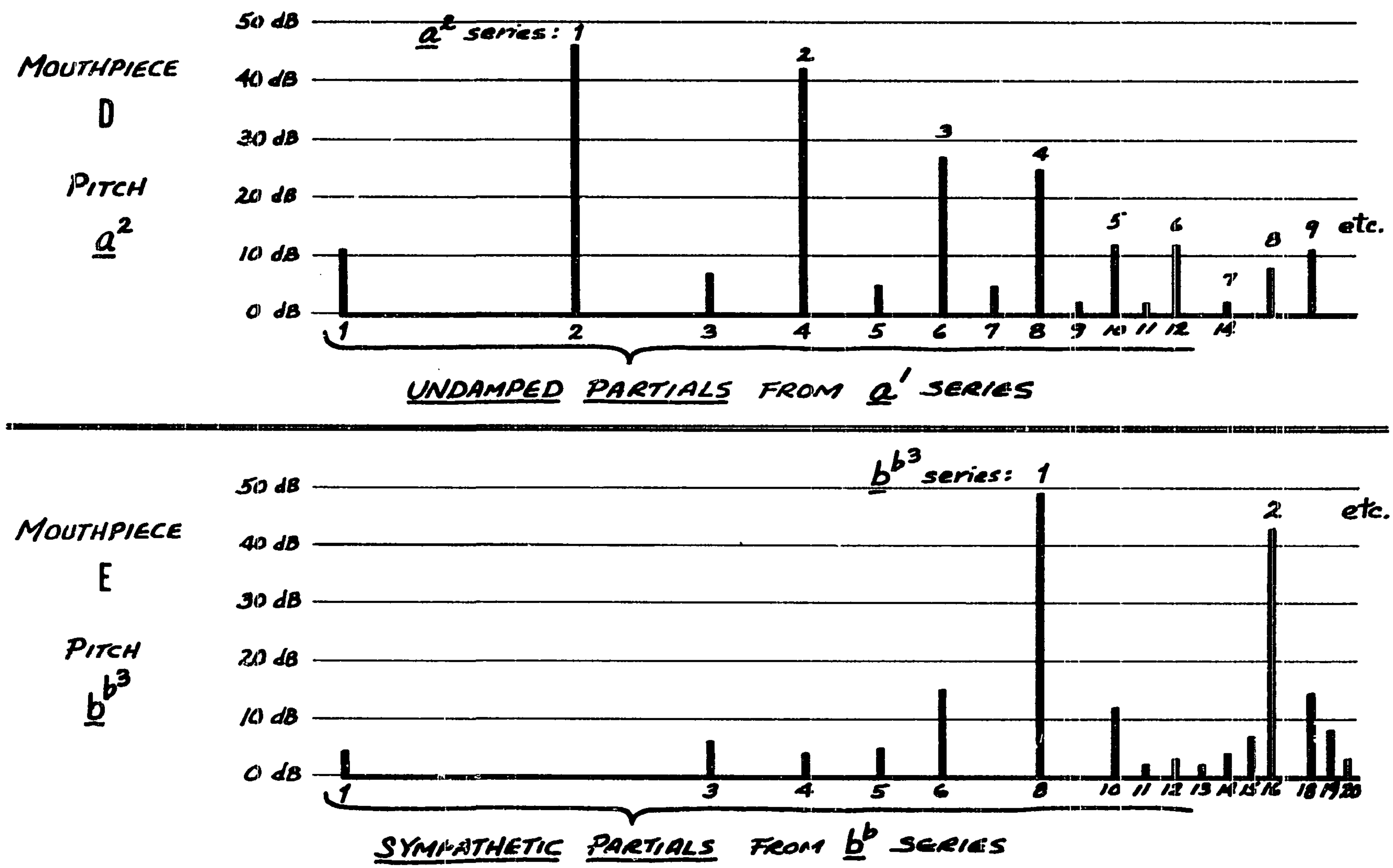


Fig. 41. Undamped and Sympathetic Partials.

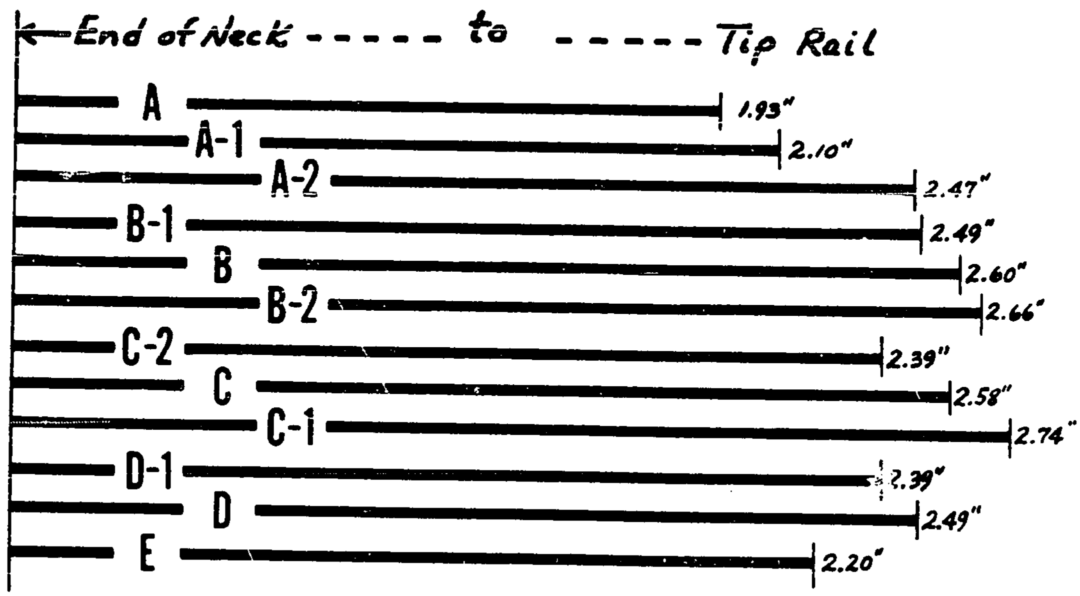
Effect of Material

Although the material of which a mouthpiece is made has an effect on tone quality, it is much less pronounced than that of the interior design. It is difficult to set up a controlled situation in which the material is the only variable. Therefore, conclusions in this area were not attempted.

Effect of Volume and Length

Mouthpiece volume remains quite constant from one mouthpiece design to another. It seems that there is a certain necessary volume required in order for the instrument to play in tune. This will be discussed in more detail in Chapter IV in relationship to intonation. The volume of each mouthpiece was measured from the end of the saxophone neck to the tip of the mouthpiece. The smaller chambered mouthpieces required additional length to make up the required volume. There were correlations between the length of the mouthpiece chamber and the tone quality produced. Within each basic mouthpiece type, the brightness of the mouthpiece was directly proportional to the length of the chamber. See the order of brightness for the twelve test mouthpieces on page 73. Fig. 42 shows the lengths of the twelve test mouthpieces (twice actual size).

Fig. 42. Chamber Length.



Effect of Bore-to-Table Angle

The angle of the bore center line to the plane of the table upon which the reed rests has some effect upon tone quality. In 1928 a mouthpiece design was patented in France by the Couesnon Company which made use of an extremely large angle between bore and table.[10] This design was the result of an effort to bring the tip of the mouthpiece in direct line with the center line of the bore. Fig. 43 shows a diagram of this mouthpiece design.

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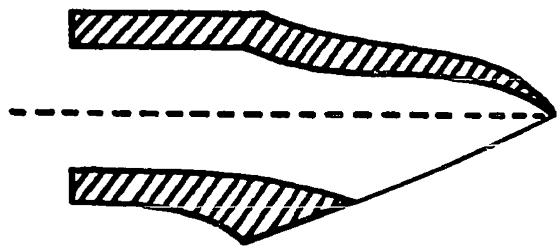
[10]Jaap Kool, Das Saxophone (Leipzig: J. J. Weber, 1931), p. 275.

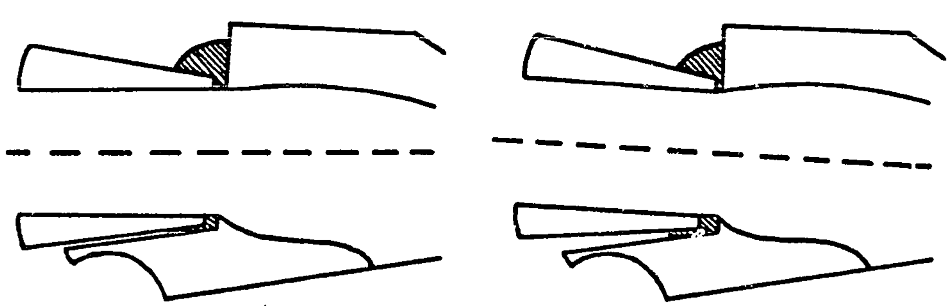
Fig. 43. Couesnon Design.



Jaap Kool described the resulting tone quality as being "rid of all sniffling and rattling in the tone. Some upper tones can now sound like a flute. The tone has lost in volume, but has lost some of its roughness and gained in warmth, tenderness, and pliancy."[11]

Mouthpiece X was used for making a test of this one variable. The bore of a hard rubber mouthpiece of Type A was cut out in such a manner as to leave the chamber and table intact. This cut out bore was then sealed to the chamber with silicone rubber so that it could pivot at the point of entry to the chamber proper and could be varied in angle as shown in Fig. 44.

Fig. 44. Variable Bore Mouthpiece.



[11]Ibid.

Spectrum graph X:A (Appendix C, p. 138) represents this mouthpiece with a bore angle of 6.5 degrees, while X:B has an angle of 11.75 degrees. The increase of the angle made the tone quality more uniform in spectrum shape throughout the range and generally made for more richness of the tone by decreasing the energy of partials 2 and 4 and increasing the energy of partial 3.

In experiments on clarinet mouthpieces, O'Brien found a general improvement in quality and playing characteristics when the bore was made closer to the table without changing the angle.[12] This type of change would also have the effect of bringing the tip opening of the mouthpiece closer to being in line with the center line of the bore. The bore angles of the twelve test mouthpieces are found in Table 5 progressing from the smallest to the greatest angle.

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[12]Harry E. O'Brien, "Mouthpiece Bores and Tone Chambers," The Clarinet, a Symphony Quarterly, I (Spring, 1952), 23.

Table 5. Bore-to-Table Angle.

D-1	3.2	degrees
C	4.6	"
B	4.7	"
A	4.75	"
B-1	4.8	"
B-2	5.1	"
D	5.2	"
C-1	5.3	"
A-1	5.4	"
A-2	5.5	"
E	5.8	"
C-2	7.8	"

A small angle seems to relate well to a certain feeling of stuffiness experienced by the performer. Mouthpiece C-2 has a much larger angle than the others. This could be the reason for the extremely even tone quality which this mouthpiece exhibits compared to the other two test mouthpieces of that general type.

Effect of Roof Contour and Baffle Shape

There is great variety in the shape of the roof contours. Within each of the five basic types of mouthpiece design studied, the maximum chamber height is inversely proportional to the brightness of the tone. The baffle area is the most important single portion of this roof line. The angle between the baffle surface and the plane of the table is inversely proportional to the brightness of the tone.

Effect of Throat Constriction and Straight Side-Walls

Mouthpieces with a constricting throat of a small size (such as B and B-2) seem to emphasize the second partial and to be generally brighter in tone quality. In the past, straight side-walls have been said to cause a very bright and unbalanced tone quality.[13] These studies reveal this to be an oversimplification. Straight side-walls tend to reduce the volume of a chamber thus forcing an increase in length (the longer the length, the brighter the sound). If a straight wall design has some other feature which allows some increase in volume, instead of by a general lengthening, it can have quite a dark sound. Mouthpieces D-1 and E are good examples of this; D-1 gains the needed volume through an increase in roof height, while E uses increased roof height and a large chamber on the inner side of the throat. Curved (concave) side-walls which are generally said to help in the production of a darker sound are thus seen as only an efficient way of increasing the volume and keeping the chamber short.

Effect of Window Length

The effect of a change in window length was studied by using mouthpiece Y. The window was varied from 35 mm.

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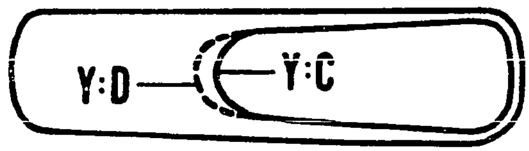
[13] Sigurd M. Rascher, "Saxophone Mouthpieces," *Instrumentalist*, IX (December, 1954), 48.

(<u>Y:C</u>) to 37 mm. (<u>Y:D</u>) as shown in Fig. 45.

Fig. 45. Window Lengthening.

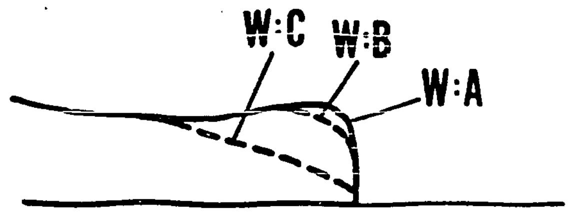


The modified mouthpiece had to be placed slightly farther on the neck cork to compensate for the slight increase in interior volume. The change resulted in a brighter, more open sound. It was somewhat harder to control in soft playing. The lengthening of the window seemed to produce a more even spectrum through the first few partials, especially in the upper register. Mouthpiece <u>C-2</u>, having the longest window of all the test mouthpieces (40 mm.), exhibits this type of spectrum shape. When the tendency of a mouthpiece is toward a weak tone in partials 2 and 4, added window length can help to correct this. In general, as mouthpieces become brighter, they tend to cause weakness in partials 2 and 4 while strengthening partial 3 and all higher ones.

Effect of End-Wall Shape

A special test was conducted on the shape of the end-wall. Mouthpiece <u>W</u> was tested with three different shapes for its end-wall, as shown in Fig. 46.

Fig. 46. End-Wall Shape.



The shape had a great effect on the resistance of the mouthpiece. W:A had the best evenness of scale and richness. W:B had a brighter quality but the scale became worse with a bad "break" between c#[2] and d[2]. Mouthpiece W:C was even brighter and had the worst scale of the three shapes. W:C was easier to control at lower dynamic levels than W:B.

Effect of Roughened Interior Surfaces

Studies have shown that air passing over a surface at high speeds produces less "wake" if the surface is roughened. The boundary layer (air closest to the surface) becomes turbulent but there is less "wake" in the air above it.[14] The surface of a golf ball is a good example of the application of this principle. In order to test its

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[14]Ascher H. Shapiro, Shape and Flow: The Fluid Dynamics of Drag (Garden City, New York: Doubleday and Company, 1961), pp. 168-71.

effect in mouthpiece design a mouthpiece with a very smooth polished interior (Z:A) was roughened by scoring lines on the baffle and roof crosswise to the flow of air. The lines were close together and extended about one inch in from the tip rail. In its roughened form (Z:B) the "edge" in the tone was reduced somewhat, but there was extreme altering of the spectrum shape for $c^{\#2}$, d^2, and f^2 of the six tones used. This does not appear to be the most efficient way of reducing "edge."

Effect of Roof and Side-Wall Thickness

There was considerable variation in the thickness of the roof and side walls of the various mouthpieces tested. This factor could not be satisfactorily analyzed, but it could have some subtle influence on tone or at least on the "feel" of a mouthpiece since the material of the mouthpiece does vibrate. Mouthpiece A had the most uniform thickness in the walls and roof.

Effect of Mouth Opening

The outer roof shape determines how wide the player must open his mouth to accommodate the mouthpiece. Table 6 shows the test mouthpieces in order from the largest to the smallest mouth opening necessary.

Table 6. Mouth Opening

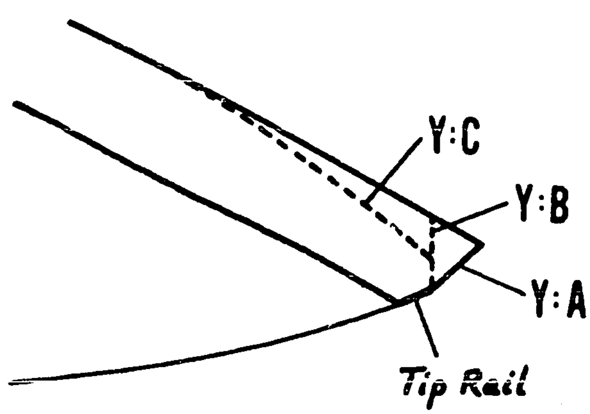
B-1	LARGEST
D-1	
A and C	
E and A-1	
B-2 and C-1	
D	
B	
C-2	
A-2	SMALLEST

The variation in mouth opening required from B-1 to A-2 is only 7/64 of an inch but the difference in "feel" to the player is great. A general darkening of the tone occurs with increased opening of the mouth; however, the inside chamber shape is a much greater influence.

Effect of Outside Beak Shape

A test was conducted to find the effect of varying the outside beak shape at the tip rail. Mouthpiece Y was used for this test. The variations used can be seen in Fig. 47.

Fig. 47. Outside Beak Shape.



The shape of Y:A has never been used on manufactured mouthpieces. Surprisingly, this shape had very good playing characteristics. The tone quality was very smooth and mellow, was easily controlled through a wide dynamic range, and was resonant. Tonguing was amazingly effortless and the attack transients were minimal. Spectrum analysis showed a very smooth energy drop-off in the partial structure of b^b and a good "break." The change to Y:B resulted in a weakening of the high register, a brighter sound, and more air noise in the tone, although the tone was still mellow and resonant. Spectrum analysis showed a less even scale and a bad "break." The final change to Y:C resulted in less resistance in the mouthpiece, a brighter tone with a thin high register, a weakness of partial 2 and 4 on $c^{\#3}$, and the introduction of a "buzz" to the tone which was difficult to eliminate.

CHAPTER IV

INFLUENCE OF MOUTHPIECE DESIGN ON INTONATION

Preliminary Considerations

Building a woodwind instrument with perfect intonation is virtually impossible. If the instrument is limited in range to those tones which can be played as fundamental tones, an instrument can be built to play in tune simply by the correct placement of the tone holes. Extending this range upward requires the player to sound harmonics other than the fundamental for the various lengths of tube provided by the tone holes.

On the saxophone, fundamental pitches are normally utilized from $\underline{b}^{b}$ up to $\underline{c}^{\#2}$. Beginning with $\underline{d}^{2}$ and moving upward, the tones are produced as second harmonics of tube lengths with fundamentals an octave below. In order to produce an "overblown" pitch of this kind, the odd-numbered harmonics must be damped or cancelled out. In order for odd-numbered partials to sound, there are certain places in the instrument bore at which the air must be in a state of non-motion. By opening a small venting hole placed at one of these locations, the non-motion condition is prevented and the odd-numbered harmonics are easily cancelled out. This damping leaves only the even-numbered harmonics which form a new harmonic series an octave above the old one. Fig. 48 illustrates the damping of odd-numbered harmonics (shown as black note-heads) in order to produce a tone an octave higher.

Fig. 48. Damping of Odd-Numbered Harmonics.

Each length of tube used has its own ideal spot for the placement of this venting hole. The intonation and quality of the "overblown" tone depends upon the proper placement of this hole. Since it is impractical to have a separate hole for every note, a single hole is made to do service for several adjacent notes. The location of the hole has to be a compromise and is not equally satisfactory for the pitch and quality of all tones. The farther the hole from the ideal spot, the sharper the "overblown" pitch tends to be.

The saxophone uses two venting holes. The first serves for the chromatic tones between $\underline{d}^2$ and $\underline{g}^{\#2}$ while the second serves for the notes from $\underline{a}^2$ upward. The lowest tones served by each venting hole are the sharpest in pitch, i.e. $\underline{d}^2$ and $\underline{a}^2$. "Overblown" tones in the second register are generally slightly sharper than a true octave above the same tones of the lower register.[1] The player must bring these tones down to correct pitch as he plays.

The mouthpiece design has some effect on how pronounced these intonation tendencies of the instrument body are. Nederveen found that the mouthpiece cavity acted as a means of keeping the octaves in tune. Without such a chamber the upper tones of octaves would be much sharper.[2]

Nederveen also pointed out that the effective length of a conical instrument is not just to the tip of the mouthpiece. It is found by extending the conical instrument bore out past the end of the mouthpiece until the sides converge to a point. On the author's instrument, this focal point is 6.18 inches beyond the end of the neck.

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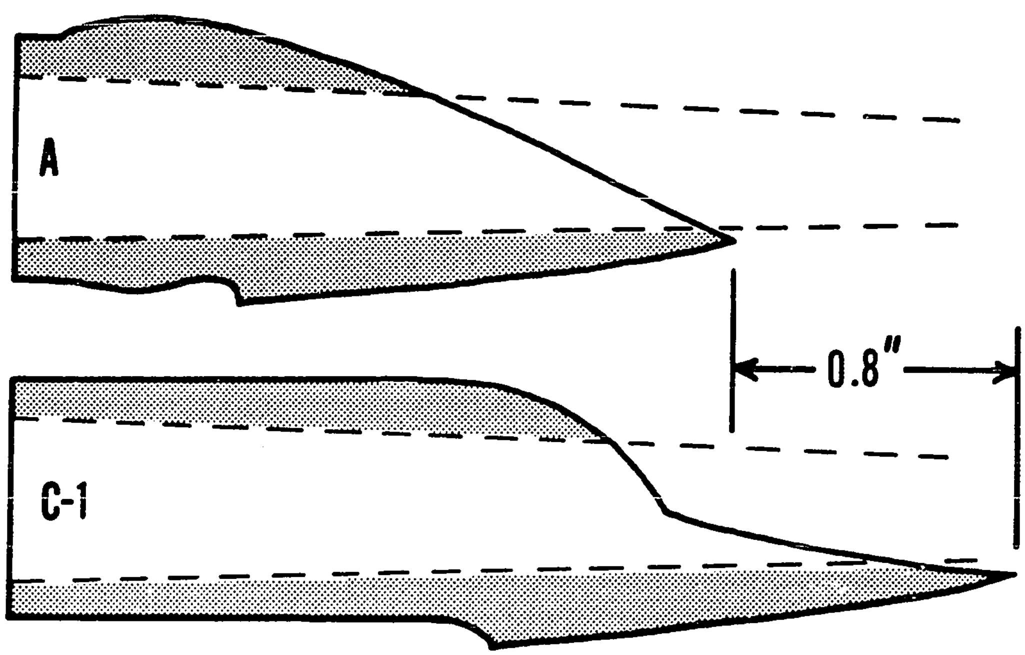
[1]Arthur H. Benade, "On Woodwind Instrument Bores," Journal of the Acoustical Society of America, XXXI (February, 1959), 139.

[2]Cornelis J. Nederveen, Acoustical Aspects of Woodwind Instruments (Amsterdam: Fritz Knuf, 1969), p. 83.

Theoretically, the mouthpiece chamber must be of sufficient volume to make up the total added volume of the cut-off portion of this cone beyond the mouthpiece.[3] The large rounded-out mouthpiece chamber for the saxophone is thus seen as a means of making up this added volume.

Fig. 49 shows a comparison of the shortest and longest mouthpiece chambers used in this study. The extension of the conical walls of the neck is shown as well as the extra volume in shading. Although the two mouthpieces are in correct tuning position on the saxophone neck, one mouthpiece is about 0.8 inches longer than the other.

Fig. 49. Shortest and Longest Chambers.



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[3]Ibid., p. 9.

Appendix A (p. 127) shows a comparison of the chamber volumes of the twelve mouthpieces used in this study. The two mouthpieces pictured in Fig. 49 had the same volume (9.4 cubic centimeters). All of the test mouthpieces but one had volumes between 9.0 and 9.5 cubic centimeters. Mouthpiece D-1 had a slightly smaller volume--8.7 cubic centimeters.

Intonation Tendencies of the Twelve Test Mouthpieces

The pitch flexibility of the saxophone allows for considerable modification of the pitch by the player. The author found that it was possible to play all of the mouthpieces in tune for all notes. Some of the mouthpieces tended to be sharper than others for tones in the second register, but they could be played in tune with a little extra effort. The intonation characteristics of a mouthpiece are more easily corrected by the player than are tone quality problems caused by mouthpiece design.

The intonation tests, described in detail in Chapter II (Test 2, p. 51) were designed in such a way that the player was disoriented tonally. This was done in an effort to obtain pitches that were in an unlipped state. The reader should bear in mind that tones in the charts of this chapter appearing to be very sharp would not be as out-of-tune in a melodic context.

Fig. 50 shows the mean frequencies of the test tones for the basic mouthpiece types represented by mouthpieces A, B, C, D, and E. These mean frequencies are the result of averaging thirty-three playings of each tone. The figure shows a fairly uniform pattern for all mouthpieces in the lower register. In the second register the differences are more pronounced. Mouthpiece C is noticeably sharper in this register. Mouthpieces A and E are very sharp as they near the top of the second register ($c^{\#3}$).

Figs. 51 through 54 show the mean frequencies for tests on all twelve test mouthpieces. These tests were performed by the author and each pitch shown is the mean of three playings of the tone. Mouthpieces B-1 and C-1 show unusually large intervals for the $c^{\#2}$-d^2 break. Mouthpiece E has an unusually small break.

Several of the single modification tests also produced noticeable differences in the size of the $c^{\#2}$-d^2 break and in the general sharpness of d^2. Because of the nature of these tests, only a single playing was possible for each test tone. The mouthpiece modifications which seemed to reduce the sharpness of the pitch d^2 and decrease the size of the break were: roughening the baffle, lengthening the window and increasing the table-to-bore angle.

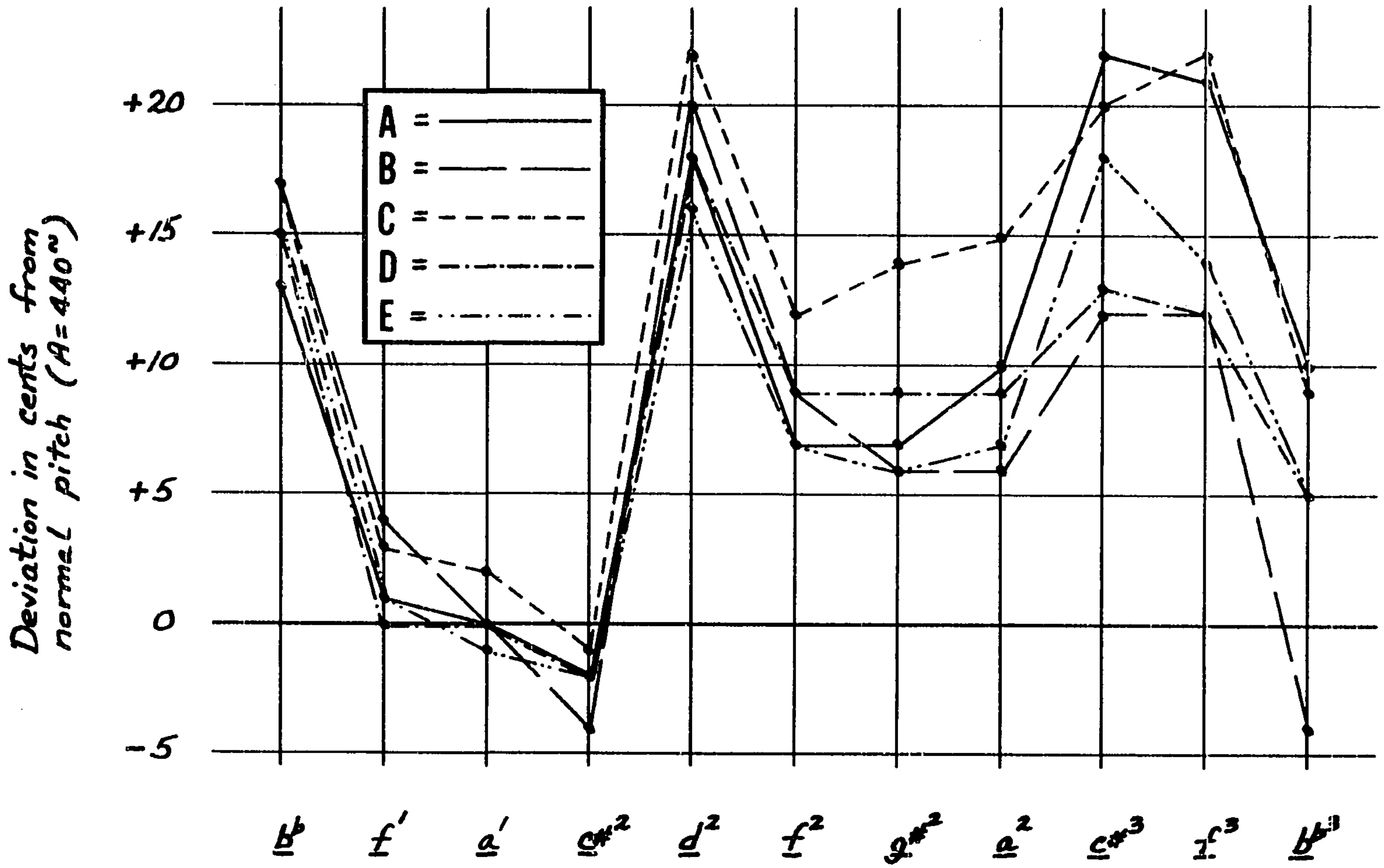


Fig. 50. Intonation: A, B, C, D and E.

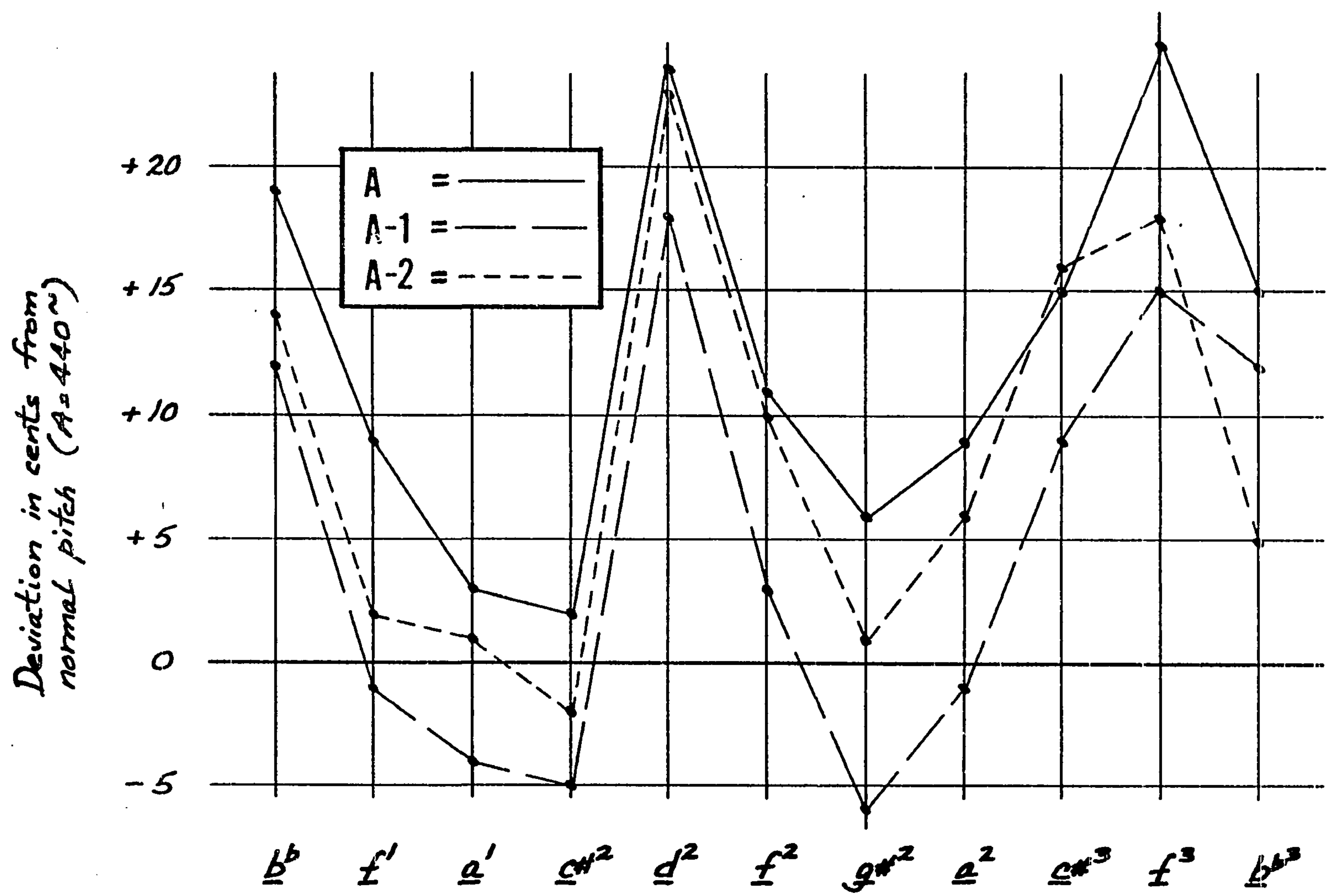


Fig. 51. Intonation: A, A-1 and A-2.

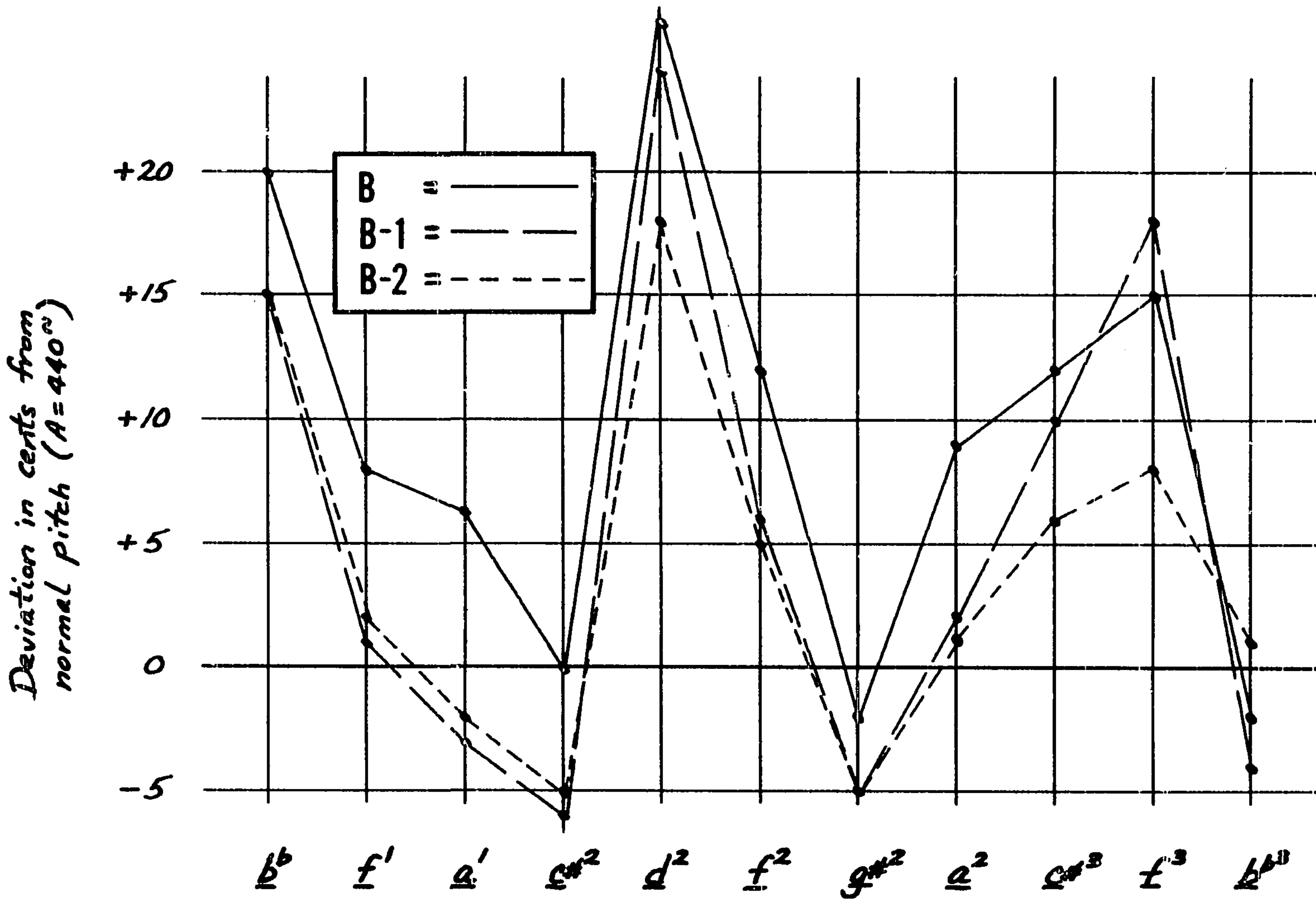


Fig. 52. Intonation: B, B-1 and B-2.

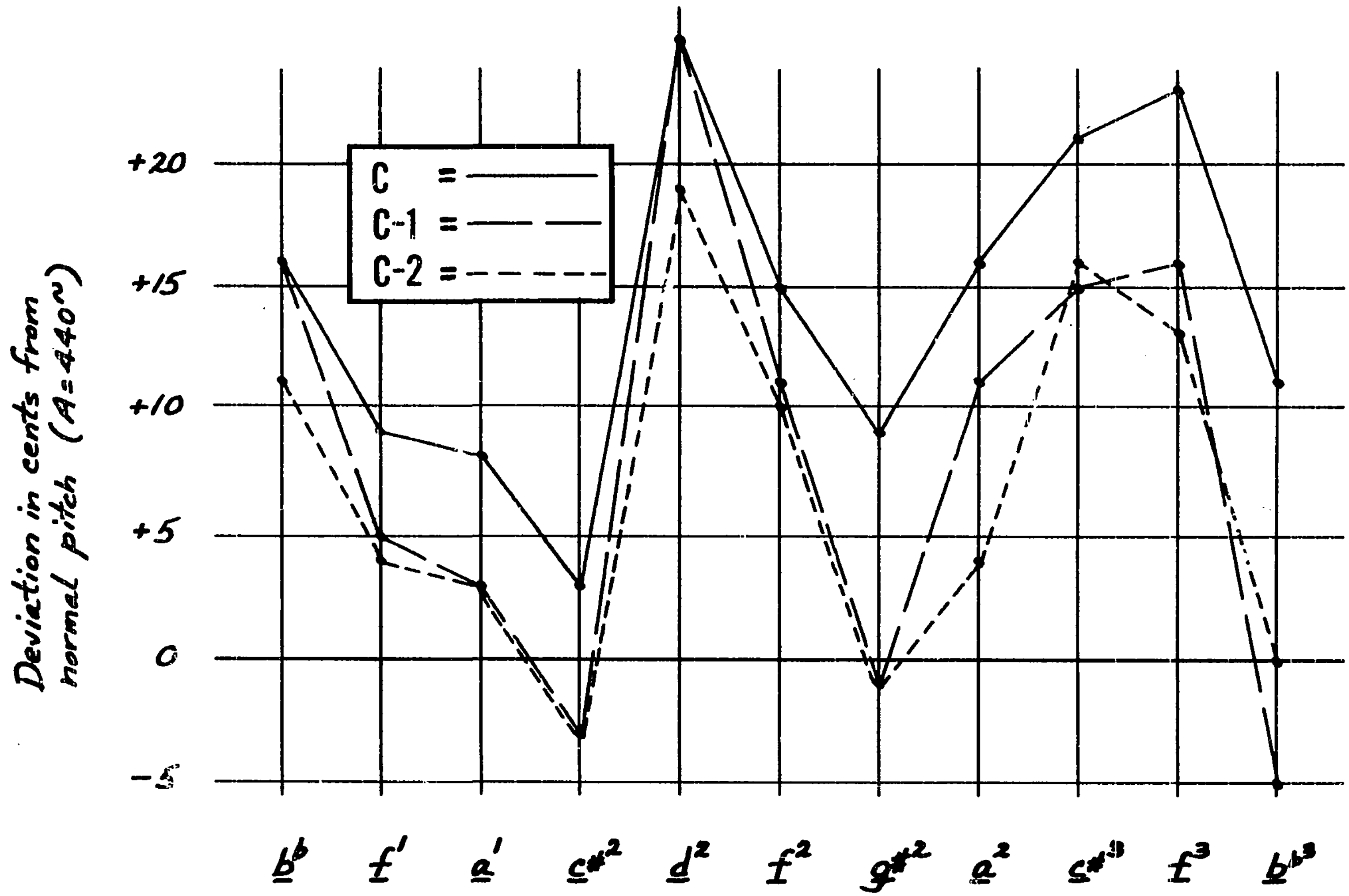


Fig. 53. Intonation: C, C-1 and C-2.

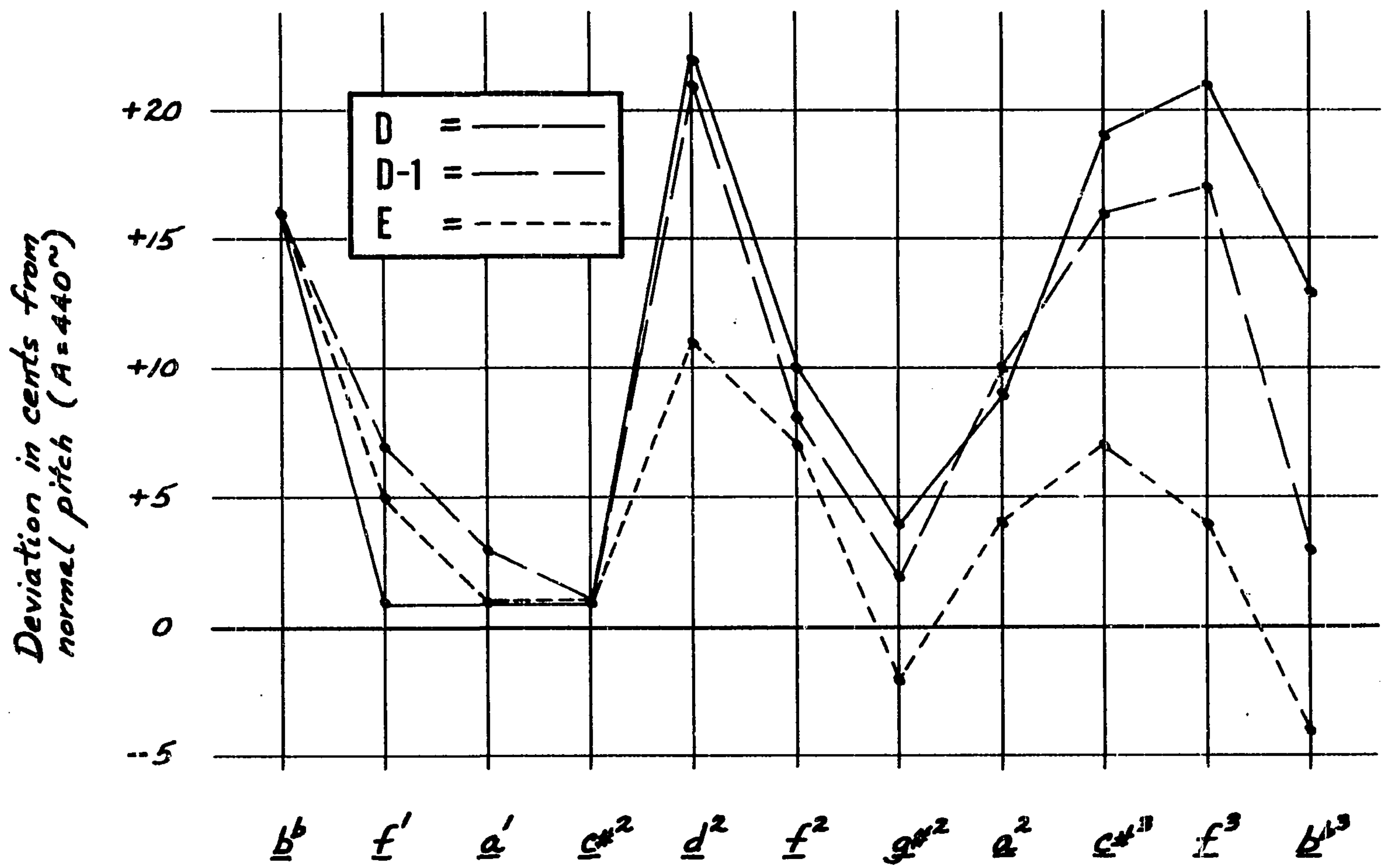


Fig. 54. Intonation: D, D-1 and E.

Effect of Dynamic Change on Intonation

Test 3 (p. 53) revealed that different designs reacted differently to changes in dynamic level. The pitch $\underline{f}^2$ was played at three different dynamic levels: mf, pp and ff. Fig. 55 shows, for each mouthpiece, the amount of sharpening which occurred when playing at the pp level and the amount of flattening at the ff level. Mouthpieces A-1 and A-2 show a marked tendency to sharpen as the dynamic shifts to the pp level. B-1, B-2, C-1 and C-2 change very little or not at all in pp playing. C-2 shows the greatest flattening when playing at the ff level. A, B-1, A-1, E, and D-1 have the least flattening.

Octave Spreading

Octave spreading, or the tendency for tones of the second register to be sharper than the same tones in the lower register, was studied for each of the test mouthpieces. Among the test tones were three sets of octaves: $\underline{f}^1$-$\underline{f}^2$, $\underline{a}^1$-$\underline{a}^2$ and $\underline{c}^{\#2}$-$\underline{c}^{\#3}$. Octave spreading generally increased as the length of the bore being used decreased. Figs. 56 through 59 show the characteristic octave spreading for each mouthpiece. Mouthpiece E was superior to all others in minimizing octave spreading.

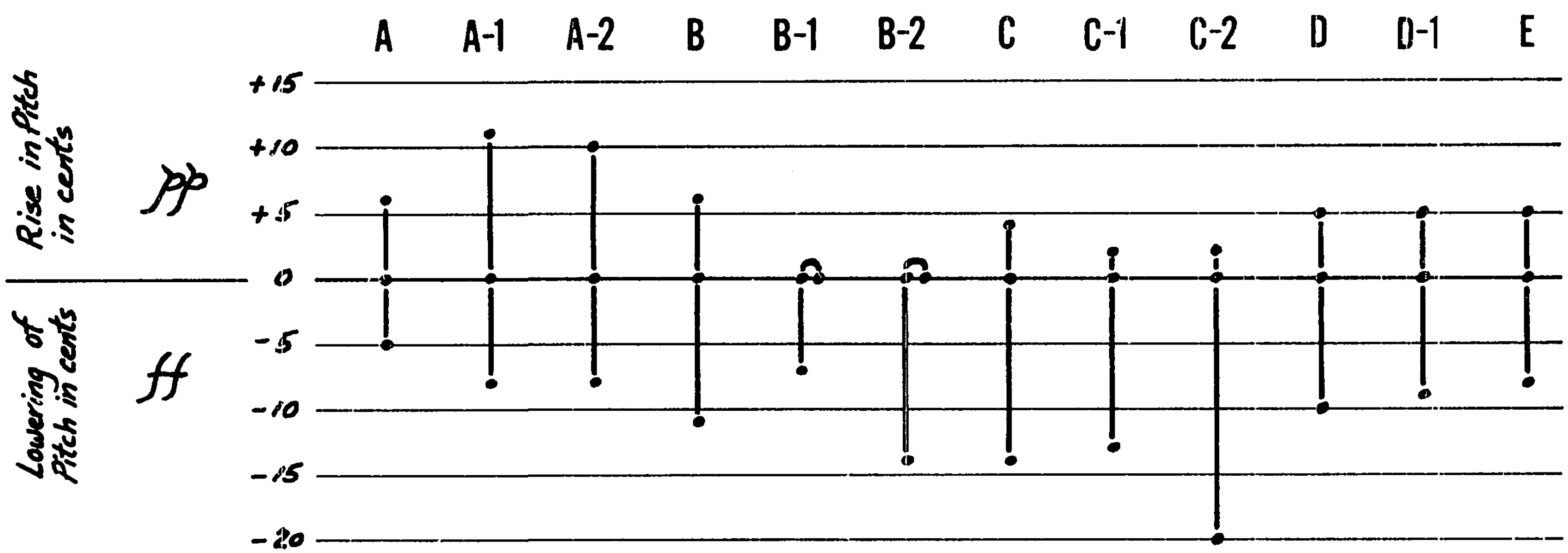


Fig. 55. Effect of Dynamic Change.

Fig. 56. Octave Spreading: A, A-1 and A-2.

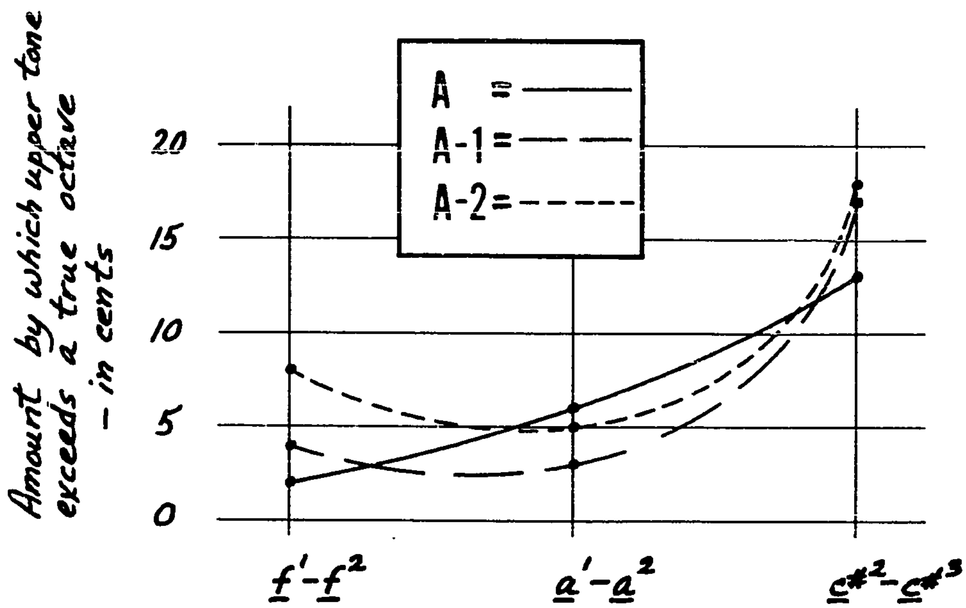


Fig. 57. Octave Spreading: B, B-1 and B-2.

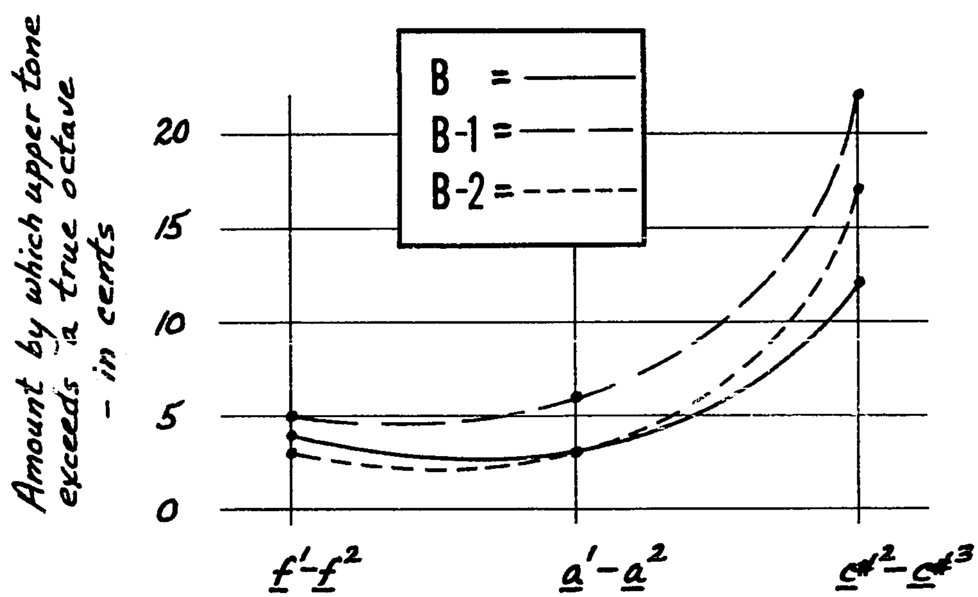


Fig. 58. Octave Spreading: C, C-1 and C-2.

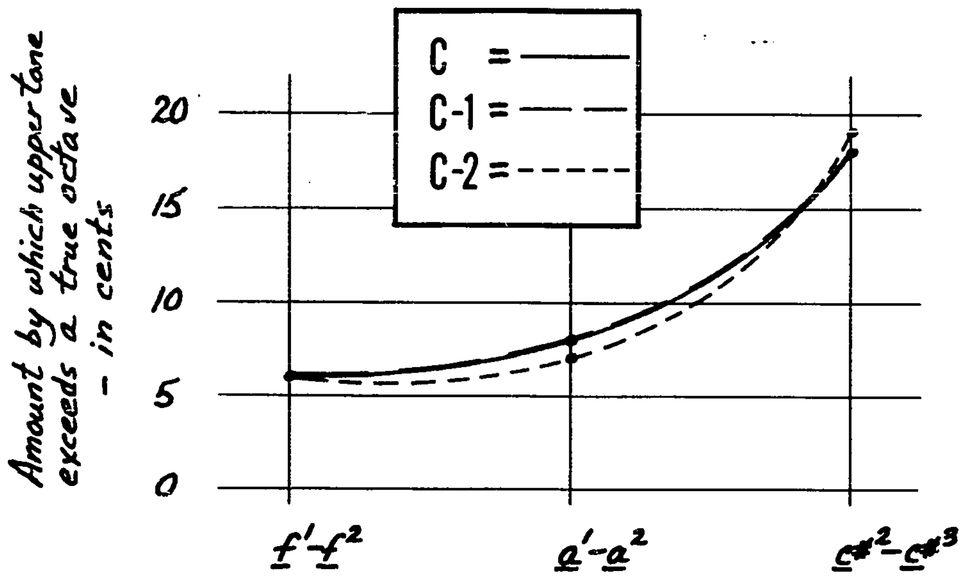
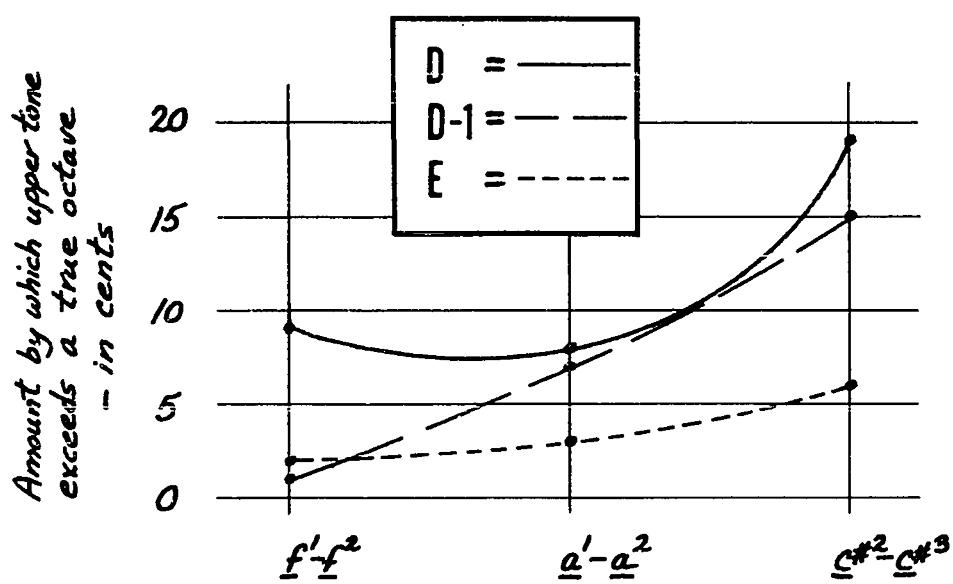


Fig. 59. Octave Spreading: D, D-1 and E.



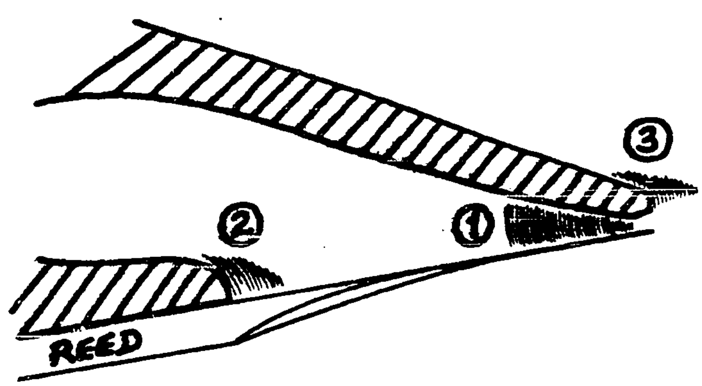
CHAPTER V

MOUTHPIECE RESISTANCE, DYNAMIC RANGE, AND CARRYING POWER

Resistance

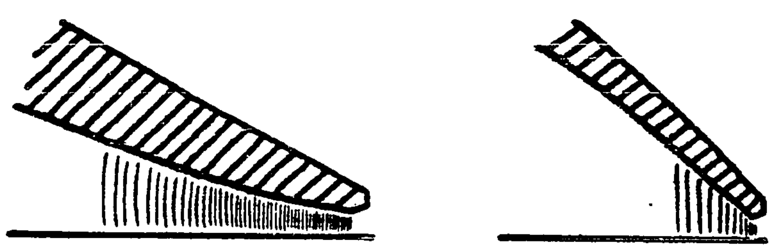
Resistance refers to the extent to which a player feels he is pushing against something as he blows air into a mouthpiece. A free-blowing mouthpiece has little resistance. Resistance gives some players a feeling of control over the tone. A certain amount of resistance helps the evenness of tone quality throughout the range of the instrument. This study located several areas of the mouthpiece chamber which affect mouthpiece resistance. These areas are shown in Fig. 60.

Fig. 60. Resistance Areas.



Area 1 has the greatest effect on the resistance of the mouthpiece. This is the area between the baffle and the reed. The air moving into the mouthpiece through this area causes the reed to close against the mouthpiece facing. Bernoulli's principle of aerodynamics explains what actually happens. This principle states that air in a moving stream has less pressure at right angles to the direction of flow. The air moves into the mouthpiece above the reed and the area between the reed and the baffle serves to channel the air. This moving air reduces the pressure above the reed. The pressure below the reed is built up somewhat since the air at that location has no place to flow. The greater pressure beneath the reed causes it to rise toward the facing. In this position little or no air can enter the mouthpiece and the reed will spring back to an open position because of its elasticity. Then air will again enter and the process will repeat itself. Fig. 61 shows two mouthpiece baffle designs.

Fig. 61. Baffle Designs.



If the baffle-to-reed angle is small, as in the mouthpiece on the left in Fig. 61, the air is channeled for a greater distance more effectively and the pressure will be reduced over a greater area along the top surface of the reed. This will cause more reduction of pressure on the top of the reed with little effort. In the mouthpiece on the right in Fig. 61, the baffle-to-reed angle is larger and the reduced pressure is confined to a smaller area close to the tip of the reed. This design will be more resistant. The resistance of a mouthpiece is directly proportional to the baffle-to-reed angle.

Area 2 in Fig. 60 is located at the end-wall. The experiment in end-wall shape discussed in Chapter III (p. 93) suggested that this area influences mouthpiece resistance. The higher the end-wall, the greater the resistance.

Area 3 is not a real part of the mouthpiece chamber but the experiments on beak shape (Chapter III, p. 96) indicated that this area can affect the resistance. The beak shape affects the channeling of the air into the mouthpiece. The radical shape first tried (Y:A in Fig. 47, p. 96) offered only moderate resistance. The modification to the shape with a very high vertical wall (Y:B in Fig. 47) produced a great increase in resistance. When the roof was thinned considerably (Y:C in Fig. 47) resistance was lessened and brightness added to the tone. Thus, resistance appears to be the result of a combination of factors.

The subjective portion of this study (Test 1, p. 50) included a ranking of the test mouthpieces in order of their resistance. All players agreed that of the basic five mouthpieces A was most resistant and E was next. There was disagreement as to the order of the last three. The author ranked all twelve mouthpieces in the following order beginning with the most resistant:

A, A-1, E, D-1, C-2, A-2, B-1, C, C-1, B, B-2, D

Dynamic Range

The psychological loudness of a tone is not merely dependent upon physical intensity. Changes in tone quality also affect the perception of loudness. An increase in the upper partial content of a tone brings with it an increase in the apparent loudness of the tone. Consequently, those mouthpieces which are brighter in quality will seem louder. It happens that brighter mouthpieces also tend to have less resistance. It is easier to play very softly on a mouthpiece with more resistance and a darker tone quality, but the lack of energy in all but the lowest partials makes it difficult for this type of mouthpiece to project a very loud tone.

The brighter mouthpieces are more difficult to control at very low dynamic levels. The twelve test mouthpieces may be categorized in three groups:

1. Easy to play pp, difficult to play ff

   A D-1 B-1

2. Good control over full range

   E B-2 A-1 C-2

3. Little control at pp, easy to play ff

   C-1 B C D A-2

Carrying Power

In Test 8 (p. 59) the five basic mouthpieces were tested for "carrying power" in an outdoor experiment. The results of this test are shown in Fig. 62. For this test, three pitches were used: b^{b}, b^{b1}, and b^{b2}. This test was a simple test of sound level at distances of 25, 50, 75, and 100 feet from the instrument with the player always producing a test tone of eighty decibels at the source. Significant differences in sound level began to appear at 75 and 100 feet for the highest pitch (b^{b2}). At this distance mouthpiece A fell off considerably more than the others. In fact, its reading at 100 feet is below the ambient noise level so that its last reading cannot be considered accurate. At a distance of 100 feet, mouthpiece E also drops more than the other remaining mouthpieces. The person operating the sound-level meter at 100 feet described the tone qualities of mouthpieces A and E as "thin." The player found great differences in effort required in producing eighty decibel tones in the three different registers. For b^b a good strong mf was required, but for the upper octaves, less. The b^{b2} had to be played p to obtain an eighty decibel reading.

Three of the subjective tests yielded little usable information. There was general disagreement in the answers to the questions on tonguing, overtone series, and ease of slurring across breaks (Appendix B, p. 134). Therefore, no valid conclusions could be drawn from those answers.

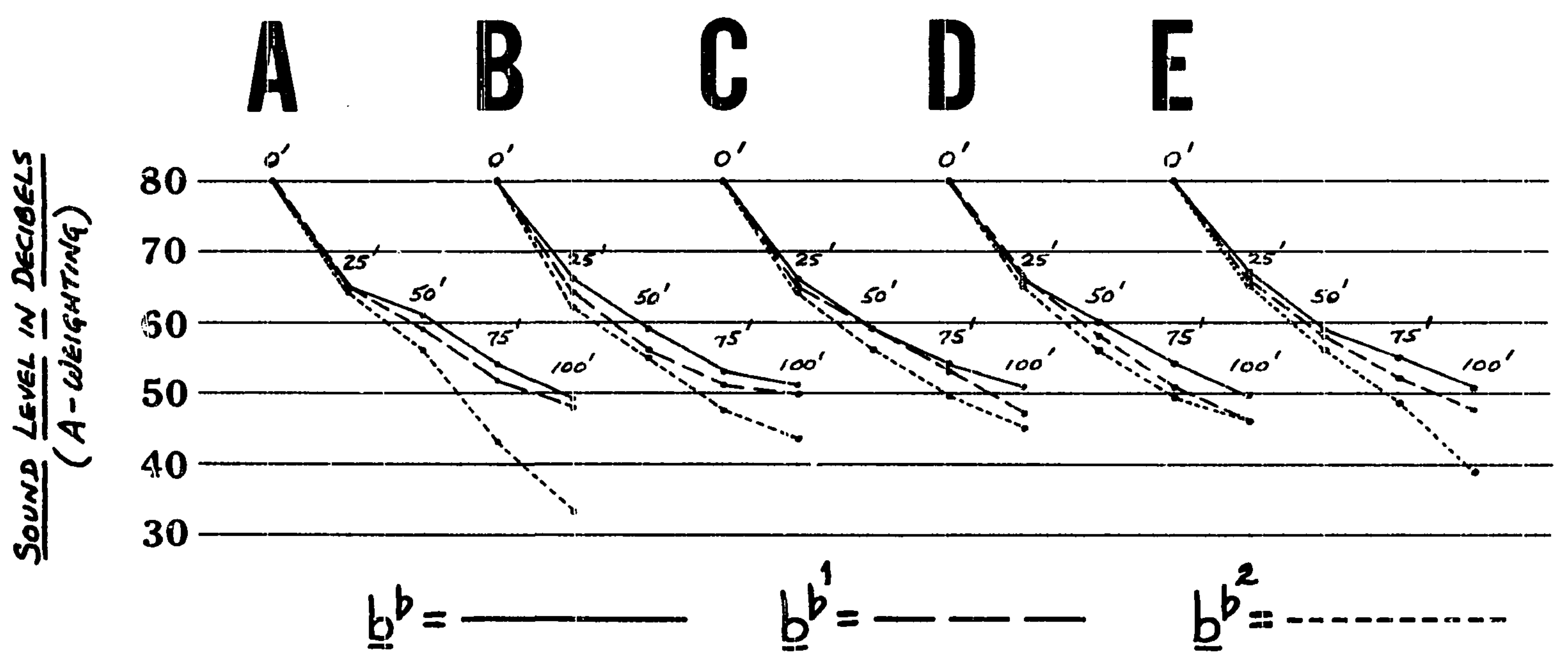


Fig. 62. Sound Levels at 25, 50, 75 and 100 Feet.

CONCLUSION

Saxophone mouthpiece design plays a large part in determining the tone quality which is produced. The player's concept, or ideal, and his control of oral cavity shape allow for differences in tone quality between performers using the same mouthpiece. The reed contour, the positioning of the mouthpiece on the saxophone neck cork, and the different amounts of lipping-down needed for various tones are also factors in the tone quality picture. The mouthpiece chamber design is, however, the most efficient means of bringing about basic changes in saxophone tone quality.

In comparing the five basic mouthpiece types used in this study, differences were observed in the way tone quality varied with changes in dynamic level. At the <u>pp</u> level, differences between mouthpieces are not pronounced. In mouthpiece chambers producing a dark tone (<u>A</u> and <u>E</u>) the upper harmonics appeared gradually as the dynamic level was increased. In chambers producing a brighter tone a more abrupt increase in upper harmonic strength was evident between <u>pp</u> and <u>mf</u> than between <u>mf</u> and <u>ff</u>.

The amount of brightness in the tone is primarily controlled by the baffle shape. A small baffle-to-reed angle tends to promote a bright tone. Since proper tuning requires about the same chamber volume from all types, the brighter types (B, C, and D) with their low roof contours tend to have longer chambers. Their smaller cross-section area necessitates greater length in order to provide the proper volume. Within each of the five basic chamber types the chamber length is directly proportional to the brightness of tone it will produce.

When the side walls are flat rather than concave, the resulting constriction is similar to that caused by the lowering of the roof height. Flat side walls usually necessitate lengthening of the chamber. Even with flat side walls the tone quality can remain quite dark if the volume of the chamber can be increased by some means other than lengthening. Two of the test mouthpieces having flat sidewalls (D-1 and E) achieve this by using a large baffle-to-reed angle and a high roof line. One of these two mouthpieces (E) also has a large inner chamber for added volume, allowing it to be still shorter in length.

Within each of the five basic types of chamber, the higher the maximum roof height is, the darker the tone will be. Two other design factors contribute slightly to the brightness of the tone: the length of the window and the thickness of the roof at the tip of the mouthpiece. Lengthening the window increases the brightness of the tone, and decreasing the thickness of the roof has a similar effect. Because of their outside shape, different mouthpieces require slightly different openings of the player's mouth. A larger opening produces a darkening effect upon the tone because of the slight enlargement of the oral cavity.

Evenness of tone quality throughout the range of the saxophone depends upon several factors. The most important of these is mouthpiece resistance. Resistance is primarily related to the baffle shape; a small baffle-to-reed angle gives less resistance than a large angle. Mouthpieces with greater resistance within the chamber have the best uniformity of tone quality. A high end wall adds to the resistance of mouthpieces of Type A. Resistance can be increased by having a thick vertical wall on the outside of the mouthpiece tip. However, this sort of resistance is detrimental to the evenness of tone quality.

Another characteristic of mouthpieces which is related to resistance is dynamic range. If a mouthpiece has a great amount of resistance (A, D-1, and B-1), it is generally easier to play with control at low dynamic levels, but it is difficult to project a loud tone. Mouthpieces which are more free-blowing (C-1, B, C, D, and A-2) can play loudly with ease, but are harder to control in soft playing. Mouthpieces with a moderate amount of resistance (E, B-2, A-1, and C-2) give the widest range of control.

The performer can exercise more control over intonation than he can over tone quality. While certain mouthpieces require more effort in pitch adjustment, it is possible to accomplish this for all types. For this reason, it is preferable to consider tone quality of primary importance in the selection of a mouthpiece type.

Intonation testing indicated that mouthpieces with shorter chamber lengths tend to be the sharpest on the upper tones of the second register; however, Type C mouthpieces are quite sharp for the entire second register. While generally giving the brightest tone, Type C mouthpieces have the worst problems of intonation.

The size of the $c^{\#2}$-d^{2} break differs from design to design. The order by mouthpiece basic type from smallest break to largest is: E, D, A, C, and B. The tendency of this interval to be larger than an equal-temperment minor second is not the greatest determining factor in making the break obvious to the ear. The matter of evenness of tone quality across the break outweighs it. For this reason, the feeling of a good or bad break does not correspond directly to the size of the break. Both lengthening the window and increasing the bore-to-table angle had the effect of reducing the size of the break.

The pitch of a saxophone tone tends to go sharp as the dynamic level of a tone is diminished and to go flat as it is increased. The mouthpiece design has an effect upon these tendencies. The tendency of mouthpieces to go sharp was limited to a maximum of only six cents for all of the test mouthpieces except two of Type A (A-1 and A-2). This small interval is easily corrected by the player. The two exceptions are more difficult to play in tune at low dynamic levels. It is more difficult for a player to keep the pitch from going flat when playing loudly. Mouthpieces of Types A, E, and D had moderate flatting, but Types B and C had extreme flatting (up to twenty cents for C-2).

The octave spreading between the two registers is minimized in the combination chamber of mouthpiece E.

In the outdoor carrying power experiment the darker mouthpieces carried less well at greater distances, especially for higher pitches. Further studies in auditorium situations would help to clarify this subject.

All of the testing for this thesis was carried out on alto saxophone mouthpieces under the assumption that the findings would apply equally to the other sizes of saxophones. Further study might show that the effects of different mouthpiece designs are slightly different for instruments of different sizes.

The presence of undamped harmonics and "accessory harmonics" in the saxophone tone suggests a new theory of tone quality for woodwind instruments. In this theory the relationship of each tone to the total length of the instrument becomes important. Further research in this area should prove of great value in clarifying observable phenomena of woodwind instrument tone quality.

It is hoped that the reader can, with the facts provided by this study, choose a mouthpiece which will most easily furnish the variety of tone quality which he desires. Certain difficulties will be encountered in areas other than tone quality when a brighter type of mouthpiece is selected. One particular test mouthpiece proved to be very successful in increasing slightly the brightness of the tone, while at the same time maintaining good evenness of quality throughout the range and expanding the dynamic range. This mouthpiece even improved upon the intonation characteristics of the original large chamber with concave side-walls. This was mouthpiece _E_.

APPENDIX A

MOUTHPIECE MEASUREMENTS

In order to construct accurate drawings for the test mouthpieces (pp. 26 - 37), many measurements were taken. Those which may be useful to the reader are given in this appendix.

	Identifying Marks	Material	Density (grams per cubic centimeter)
A	Martin	Rubber	1.25
A-1	Rascher	Rubber	1.28
A-2	Brilhart	Rubber	1.41
B	Vandoren "Perfecta"	Rubber	1.31
B-1	France	Rubber	1.27
B-2	Selmer "Soloist"	Rubber	1.22
C	Gomarico	Rubber	1.20
C-1	Larsen	Rubber	1.24
C-2	Brilhart "Level-Air"	Steel	6.25
D	Brilhart "Ebolin"	Plastic	1.33
D-1	(None)	Rubber	1.54
E	"Meliphone Special"	Rubber	1.41
W	Buescher "True-Tone"	Rubber	1.22
X	Martin	Rubber	1.33
Y	Selmer (Paris)	Rubber	1.24
Z	Brilhart "Ebolin"	Plastic	1.33

	Bore-to-Table Angle (in degrees)	Chamber Volume (in cubic centimeters)
A	4.75	9.4
A-1	5.4	9.3
A-2	5.5	9.5
B	4.7	9.4
B-1	4.8	9.3
B-2	5.1	9.4
C	4.6	9.0
C-1	5.3	9.4
C-2	7.8	9.0
D	5.2	9.3
D-1	3.2	8.7
E	5.8	9.0
W	5.7	9.3
X:A	6.5	9.3
X:B	11.75	9.3
Y	6.3	9.3
Z	5.2	9.3

Bore Measurements Before Reaming

	Original Bore	Open End (in inches)	Inner End (in inches)
A	Cylindrical	.6250	.6250
A-1	Tapered	.6240	.6210
A-2	Cylindrical	.6250	.6250
B	Tapered	.6290	.5930
B-1	Tapered	.6170	.5925
B-2	Tapered	.6340	.6260
C	Tapered	.6330	.6090
C-1	Tapered	.6310	.5770
C-2	Cylindrical	.6250	.6250
D	Tapered	.6260	.6000
D-1	Cylindrical	.6250	.6250
E	Tapered	.6110	.5830
W	Cylindrical	.6100	.6100
X	Cylindrical	.6250	.6250
Y	Cylindrical	.6200	.6200
Z	Tapered	.6260	.6000

	Chamber (larger than bore)		Throat (smaller than bore)	
	Maximum Height (inches)	Maximum Width (inches)	Maximum Height (inches)	Maximum Width (inches)
A	.6960	.6960	---	---
A-1	.6780	.6960	---	---
A-2	.6415	.6415	---	---
B	---	---	.4850	.4850
B-1	---	---	.5480	.5300
B-2	---	---	.4610	.4290
C	---	---	.5490	.5040
C-1	---	---	.5880	.4740
C-2 (chamber is same as bore)			.6250	.6250
D	---	---	.5810	.4880
D-1	.6530	---	---	.3940
E	.7150	.7150	.5860	.4215
W	.6920	.7020	---	---
X	.6830	.7080	---	---
Y	.6820	.7000	---	---
Z	---	---	.5810	.4880

Roof Curvature

This table gives the roof height at the following distances from the inner edge of the tip rail: (all measurements are given in inches)

	.0000	.0695	.1390	.2085	.4615	.7145	.9675	1.2205
A	.0600	.0920	.1310	.1730	.3230	.4565	.5755	.6745
A-1	.0610	.0930	.1215	.1580	.2840	.4115	.5245	.6295
A-2	.0640	.0730	.0845	.1030	.1980	.3190	.4306	.5390
B	.0640	.0785	.0980	.1205	.2130	.3110	.4180	.5470
B-1	.0640	.0815	.1050	.1325	.2470	.3660	.4845	.5970
B-2	.0640	.0765	.1000	.1230	.2145	.3075	.3945	.4680
C	.0615	.0780	.0915	.1100	.1740	.2655	.4040	.5690
C-1	.0650	.0760	.0865	.0985	.1530	.2195	.3090	.5675
C-2	.0660	.0920	.1090	.1245	.1725	.2160	.2625	.6405
D	.0640	.0775	.0945	.1115	.2170	.3350	.4430	.5430
D-1	.0650	.0810	.1120	.1395	.2675	.3895	.5030	.6075
E	.0640	.0890	.1220	.1575	.2970	.4210	.5340	.6215
W	.0600	.0900	.1260	.1610	.2855	.4085	.5255	.6270
X	.0660	.0820	.1125	.1515	.3055	.4570	.5760	.6815
Y	.0610	.0870	.1175	.1475	.2745	.3965	.5130	.6185
Z	.0640	.0775	.0945	.1115	.2170	.3350	.4430	.5430

	Window Length	Window Width: At Tip Rail	Window Width: One Inch in from Tip Rail

All measurements are in millimeters.

	Window Length	At Tip Rail	One Inch in from Tip Rail
A	34.50	14.25	12.50
A-1	33.50	14.00	11.50
A-2	35.50	13.75	11.50
B	35.00	14.00	11.75
B-1	33.50	14.00	12.25
B-2	37.25	15.00	12.50
C	36.25	14.00	11.50
C-1	37.75	15.00	13.00
C-2	40.00	14.75	12.50
D	39.00	14.50	12.00
D-1	37.25	13.50	12.00
E	37.50	15.25	12.50
W	35.50	14.00	11.50
X	34.50	14.00	12.00
Y:A, Y:B & Y:C	35.00	14.00	11.50
Y:D	37.00	14.00	11.50
Z	39.00	14.50	12.00

APPENDIX B

TEST FORMS AND INSTRUCTIONS

Two different tests were carried out on the five basic mouthpiece types by the eight subjects. The mouthpieces representing the basic types were A, B, C, D and E. One test covered subjective analysis from the viewpoint of the performer. The other tested the intonation tendencies of each mouthpiece. The instructions and questions for these tests follow.

Subjective Analysis Test

You will be given five mouthpieces for this test. They are labeled A, B, C, D and E. Select the mouthpiece which is closest in design to the one which you normally use. Match a reed to it. All of the mouthpieces that you will play have the same facing. Mark a line on the bark of the reed to show the position of the ligature on the reed so that you can set it similarly for each mouthpiece. This will assure the same vibrating length for the reed during each test.

Once you have adjusted the reed for this first mouthpiece, make no further adjustments during tests on other mouthpieces. Also, be sure that the reed is placed on the table of each subsequent mouthpiece in such a way that the tip of the reed will have the same relationship to the mouthpiece tip rail. All of the mouthpieces which you will test have the same tip rail width. The tip of the reed should, when closed against the facing, come to the outside edge of the tip rail.

Tune carefully to the pitch $\underline{f}^1$ (concert $\underline{a}^b$). Also check $\underline{f}^2$. Play for a few minutes on each of the mouthpieces in turn prior to attempting to write any comments. This will give you an overall preview of the mouthpieces which you will be comparing. You may play the mouthpieces in any order and as many times as you feel necessary to help you in the completion of the forms.

Answer the following:

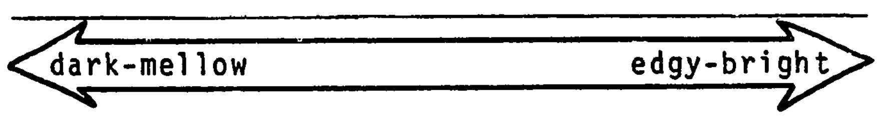
Name of Subject ______________________________.

Make __________ and Serial Number _________ of instrument used for the testing.

Which of the test mouthpieces is closest in design to the one which you usually play?

____

I. GENERAL TONE QUALITY: Place the identifying mark of each mouthpiece in an appropriate position on this line. Make additional comments on each mouthpiece on the extra blank sheets provided.



II. EVENNESS OF TONE THROUGHOUT RANGE: Check for abrupt changes between adjacent tones in either dynamic level or tone quality. Be sure to check the $\underline{c}^{\#2}$-$\underline{d}^2$ break. Rank the mouthpieces in order beginning with the most even.

______, ______, ______, ______, ______

III. RESISTANCE: Does the mouthpiece seem to restrict the amount of air-flow which you normally use, or is it more free-blowing? Rank in order beginning with the most resistant.

________, ________, ________, ________, ________

IV. DYNAMIC RANGE: Over what general range do you feel that you can control the tone? Rank the mouthpieces in order from the greatest range to the smallest range.

________, ________, ________, ________, ________

____ ppp
____ pp
____ p
____ mp
____ mf
____ f
____ ff
____ fff

V. TONGUING: Rank the mouthpieces according to tonguing characteristics. Note changes necessary in the several registers. Rank from best to worst.

________, ________, ________, ________, ________

VI. OVERTONE SERIES: How well do the tones of the overtone series on $\underline{b}^{b}$ agree in pitch with the same tones produced with regular fingerings? Rank in order from best to worst.

VII. EASE OF SLURRING ACROSS BREAKS: Check especially the slurring down across the $\underline{g}^{\#2}$-$\underline{a}^{2}$ break. Rank in order from easiest to hardest.

________, ________, ________, ________, ________

Intonation Test

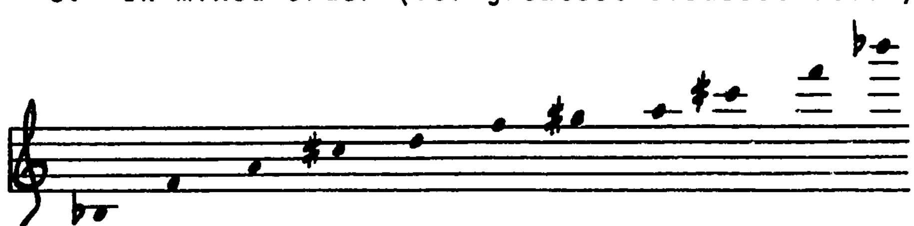
Follow all of the instructions found above with the Subjective Analysis Test. There are several additional instructions for this test.

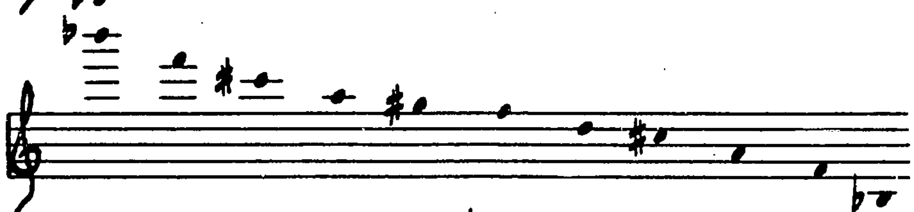
Mark mouthpiece placement in order to facilitate the computing of interior volume.

For these tests play all pitches with your mind directed toward the production of a good resonant musical tone. Do not be primarily concerned with playing "in tune." Try not to think of the pitches in relation to each other as in a melody for you will then tend to try to play each pitch "in tune."

Only eleven carefully selected pitches are to be used. They will be played in three different orders:

a. In ascending order
b. In descending order
c. In mixed order (for greatest disassociation)

a.


b.


c.


Play all pitches at a _mf_ dynamic level. Use regular fingerings for all notes. Use same fingerings for all three series of pitches. Use open $\underline{c}^{\#2}$, regular side-key $\underline{f}^{3}$ and use the fingering which has had the best intonation on your instrument for the $\underline{b}^{b3}$.

An assistant will record the pitch deviation while the tones are being played.

APPENDIX C

HARMONIC SPECTRUM GRAPHS

On the following pages are the results of the spectrum analysis of test tones from the twelve test mouthpieces and the various stages of the single modification tests.

The following points will help in interpreting the graphs:

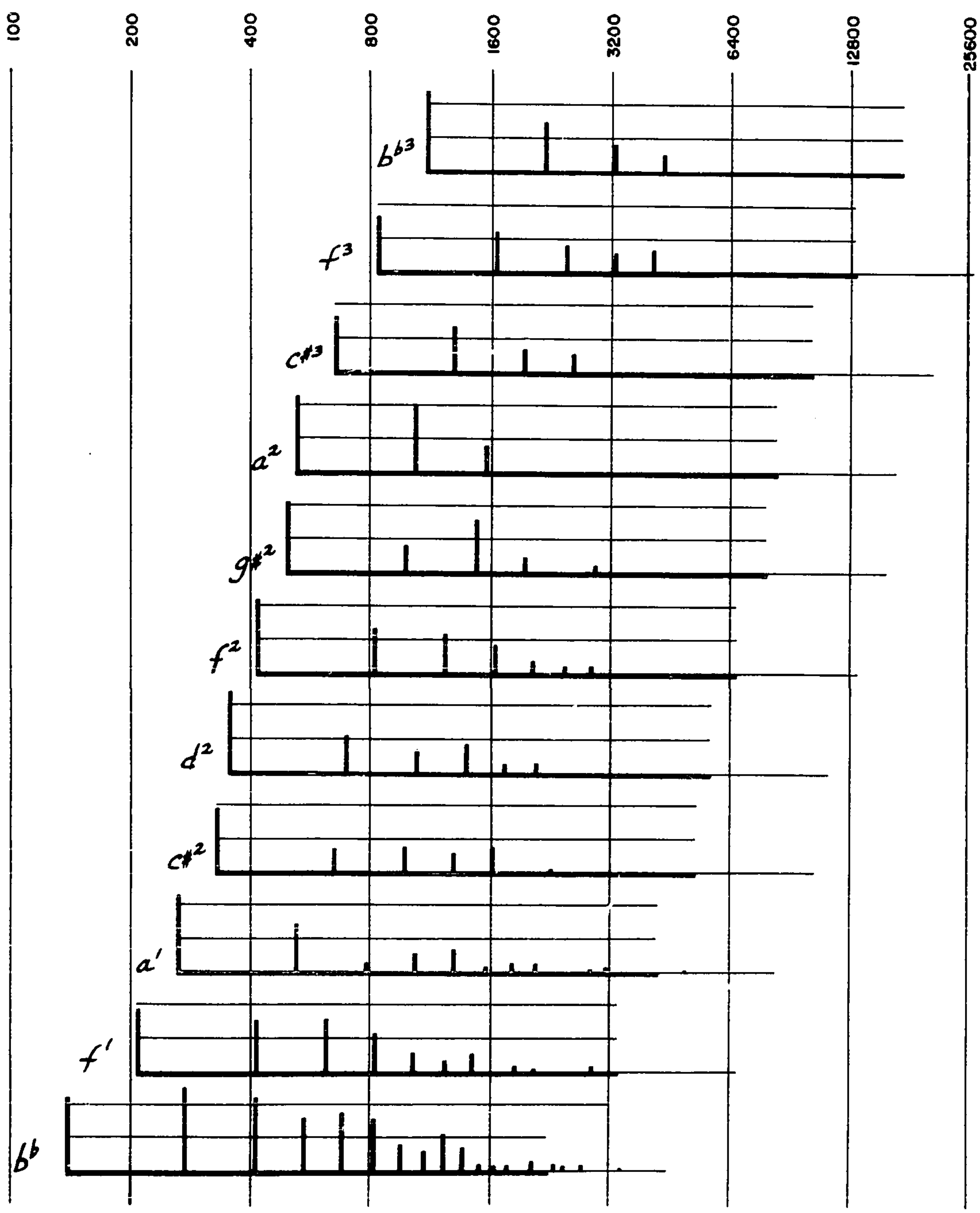
1. The test tones are each identified by name. Mouthpieces A, B, C, D, and E have eleven test tones, while all of the others have six tones as explained in the text.

2. The numbers across the top of each chart identify the frequency in Hertz of the vertical lines.

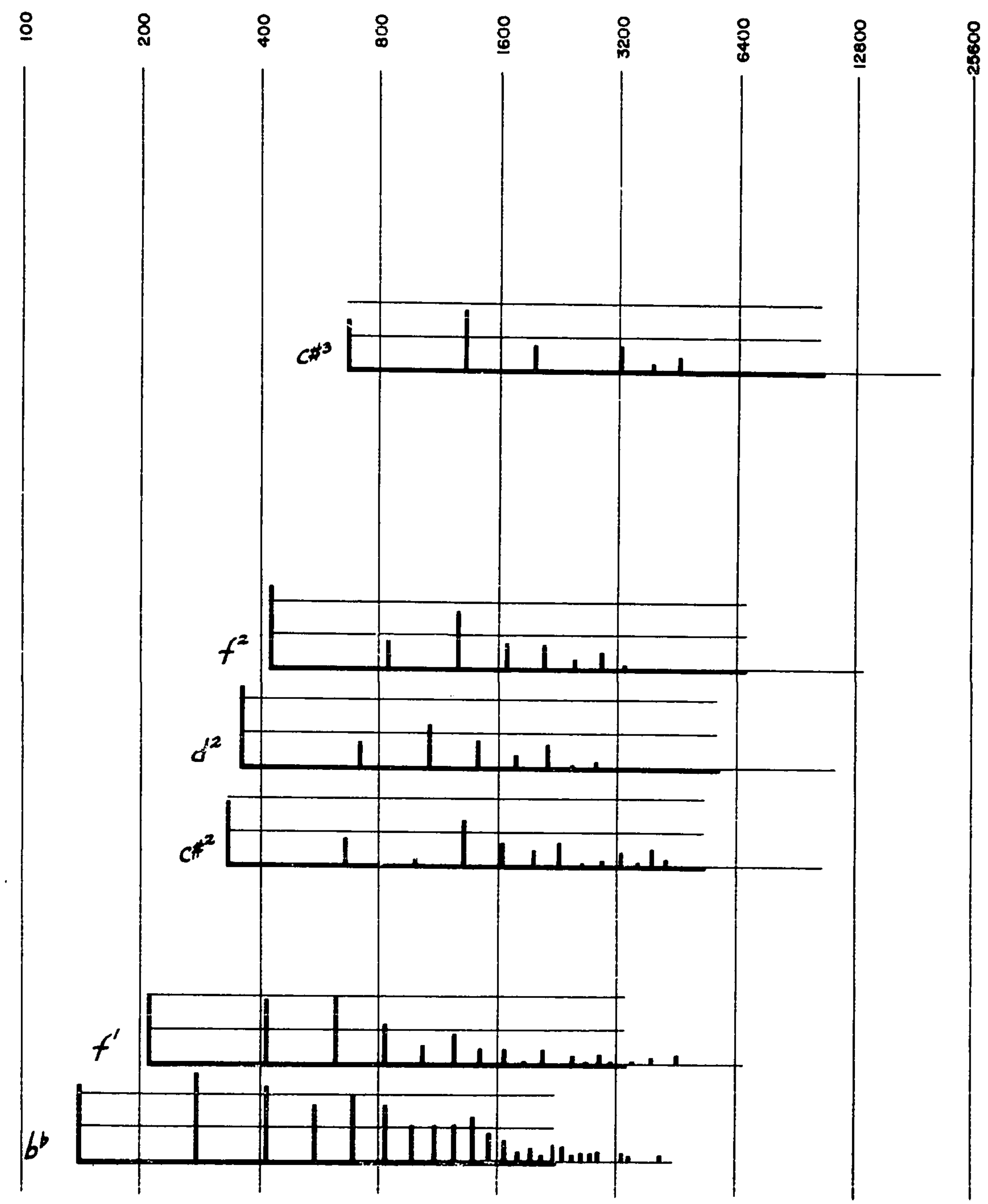
3. The spectrum for each tone is shown on a heavy base line which extends through the sixteenth harmonic. A thin continuation on this base line extends through the thirty-second harmonic. The base line represents a 10 dB sound pressure level and the two additional horizontal lines represent 30 dB and 50 dB levels.

4. A special ruler contained in a pocket inside the back cover of this dissertation will be useful to the reader. With it, specific harmonics can easily be located by number.

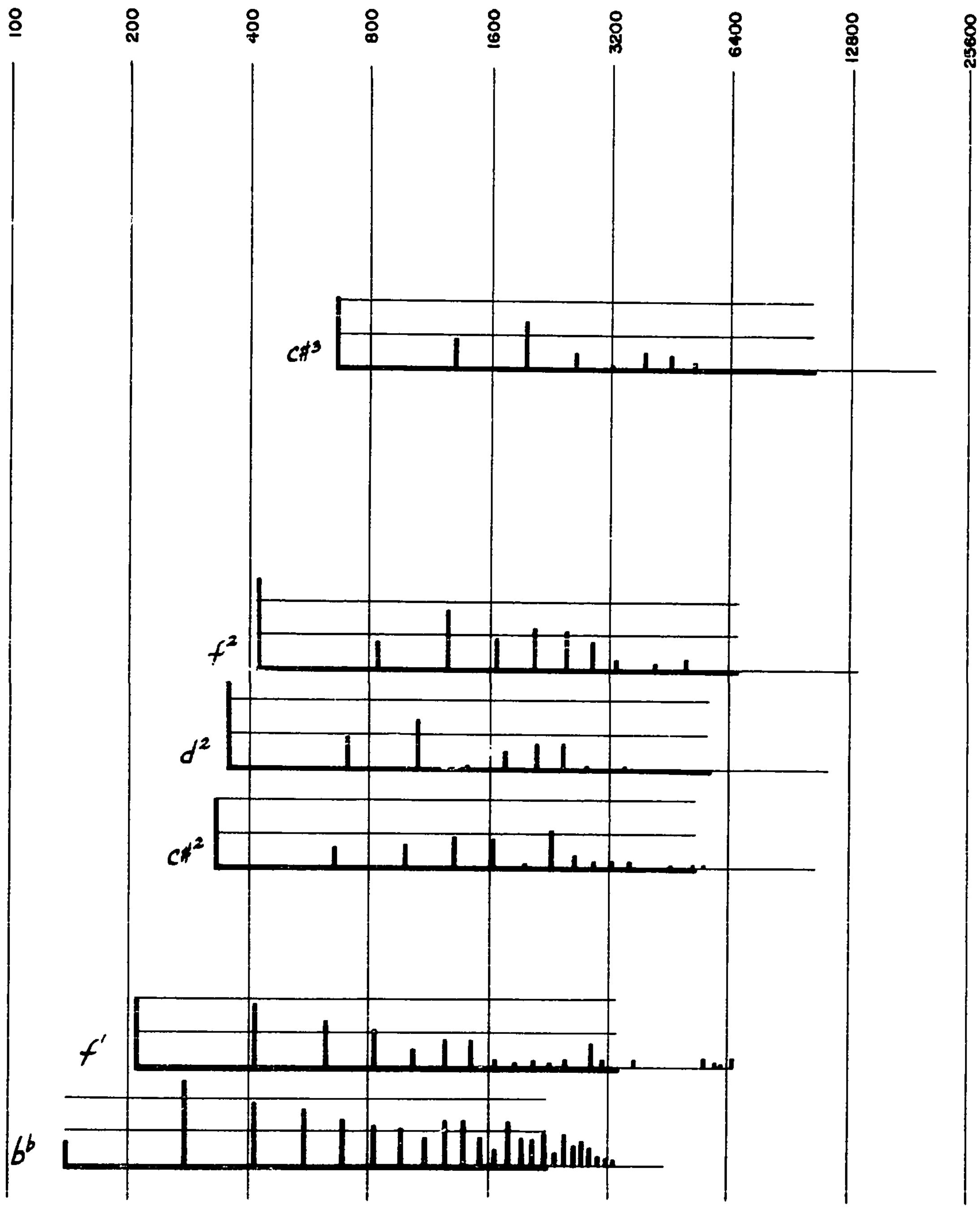
A


100
200
400
800
1600
3200
6400
12800
25600
b♭3
f3
c#3
a2
g#2
f2
d2
c#2
a'
f'
b♭

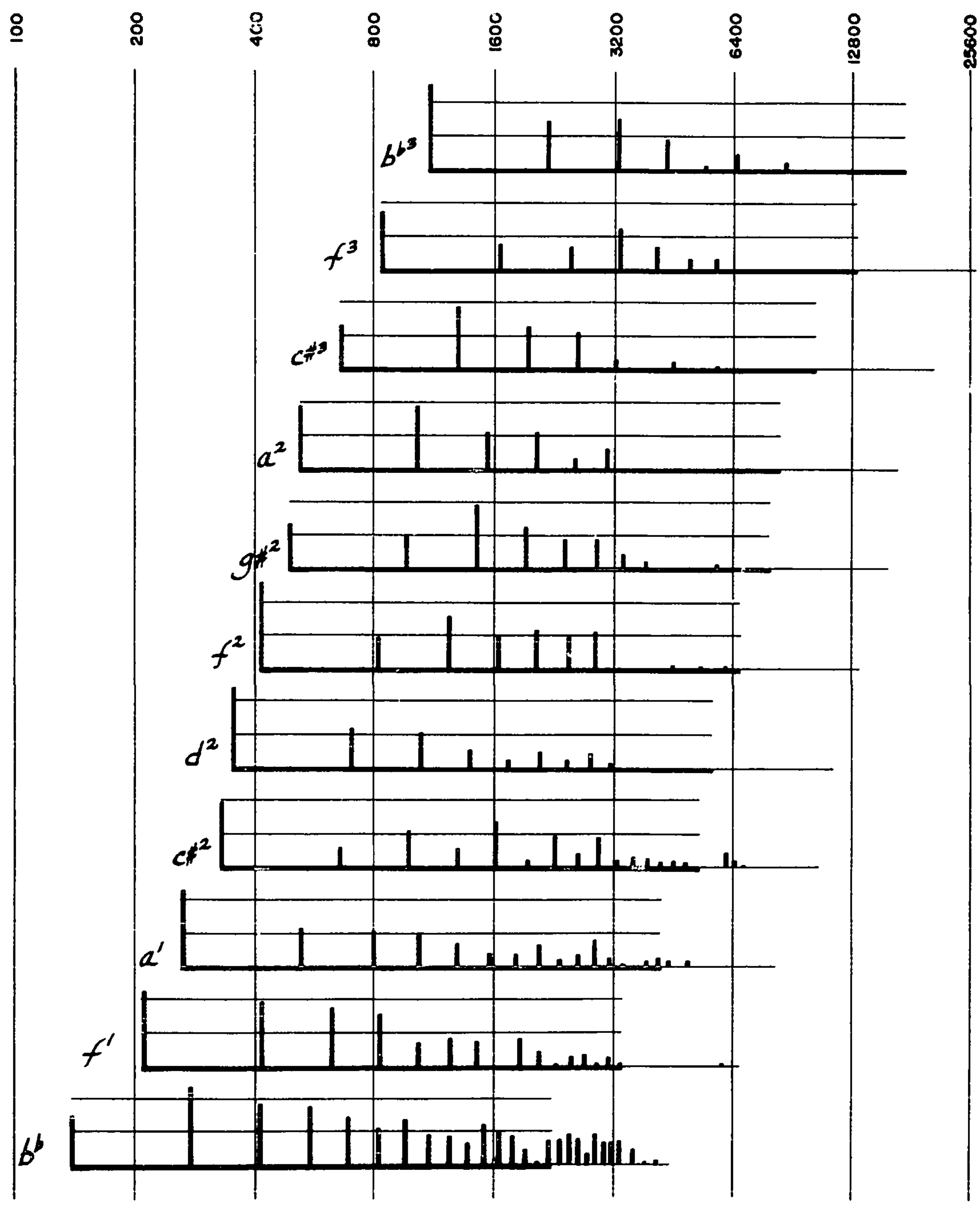
A-1



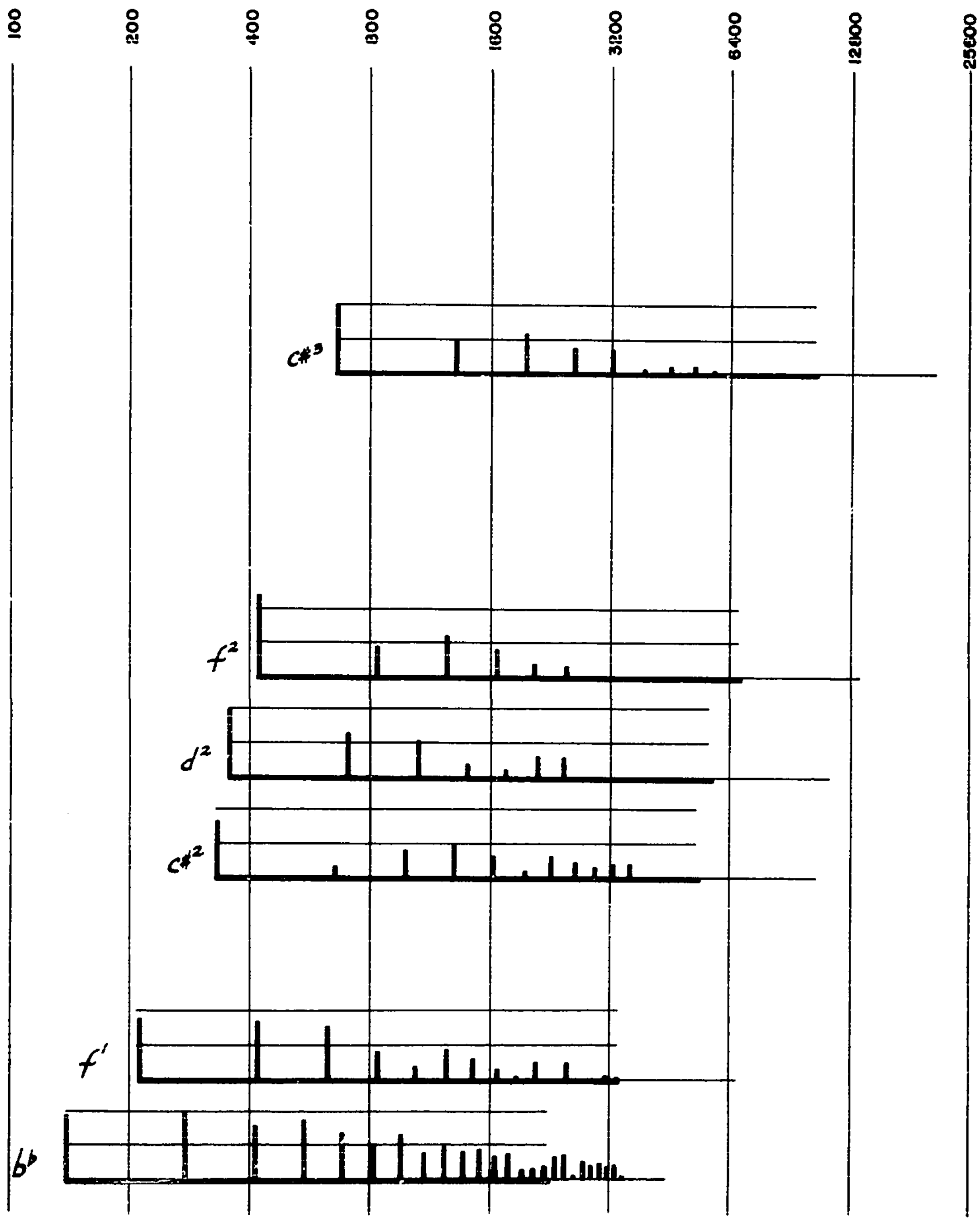
A-2



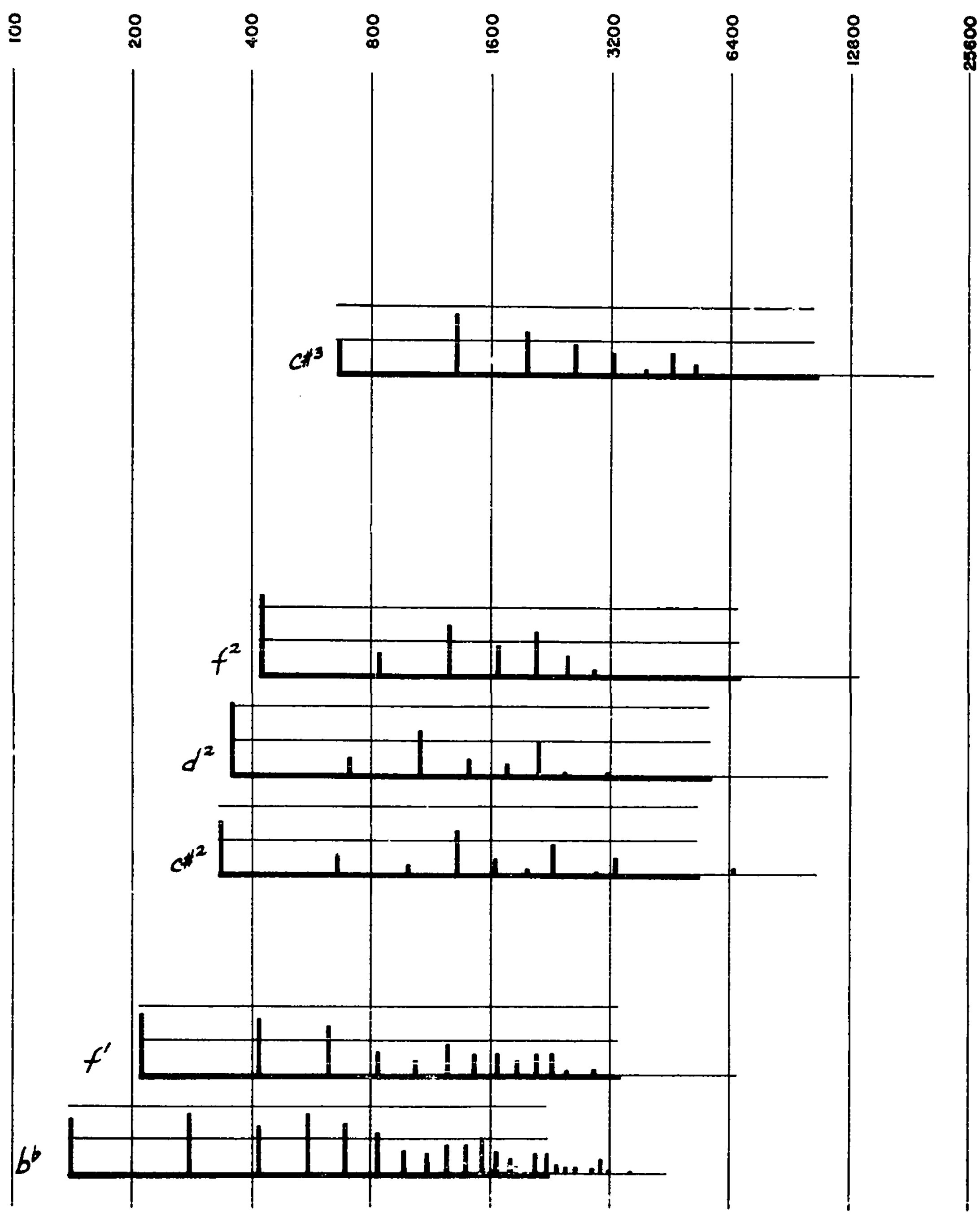
B


100
200
400
800
1600
3200
6400
12800
25600
b♭3
f3
c♯3
a2
g♯2
f2
d2
c♯2
a1
f1
b♭

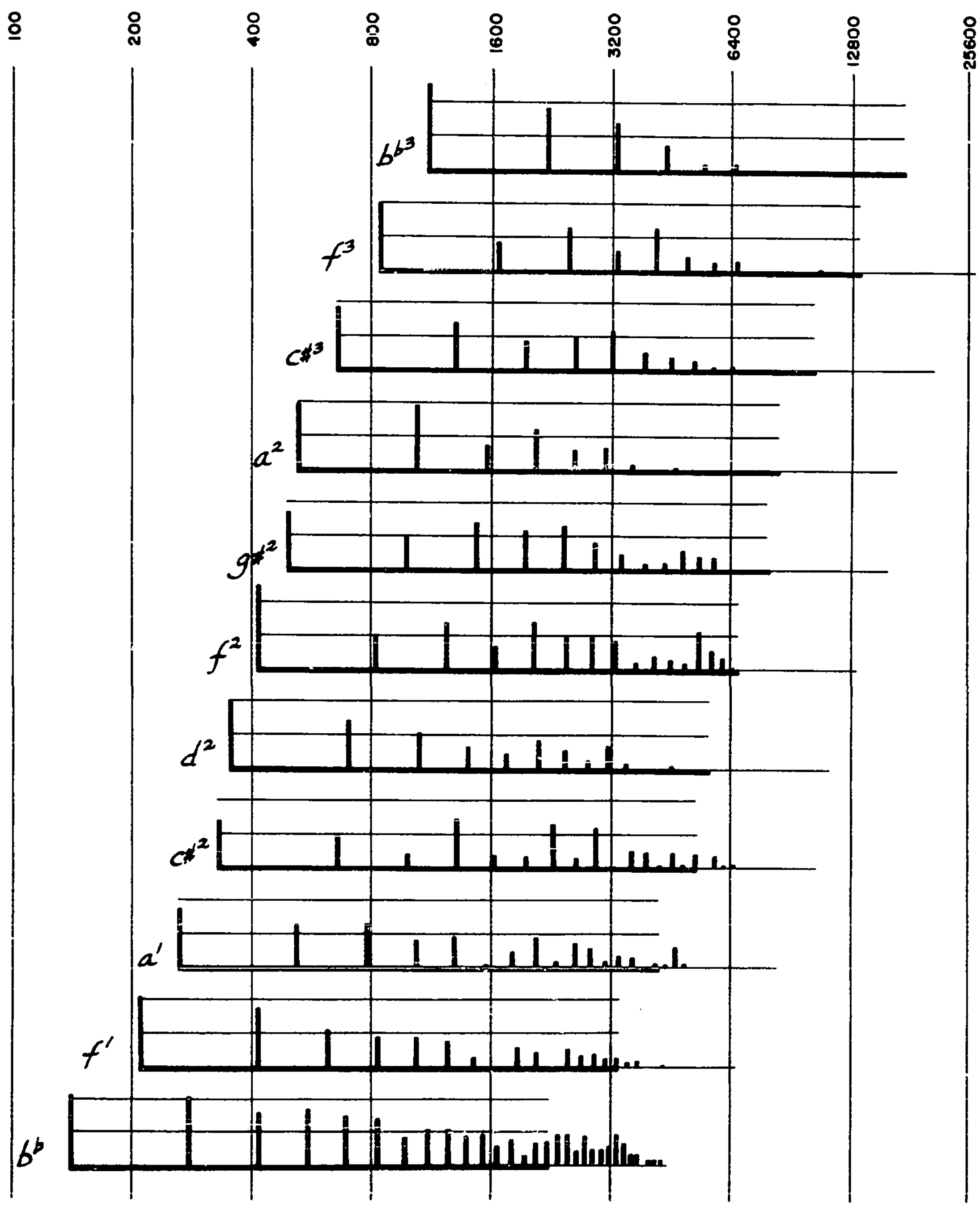
B-1



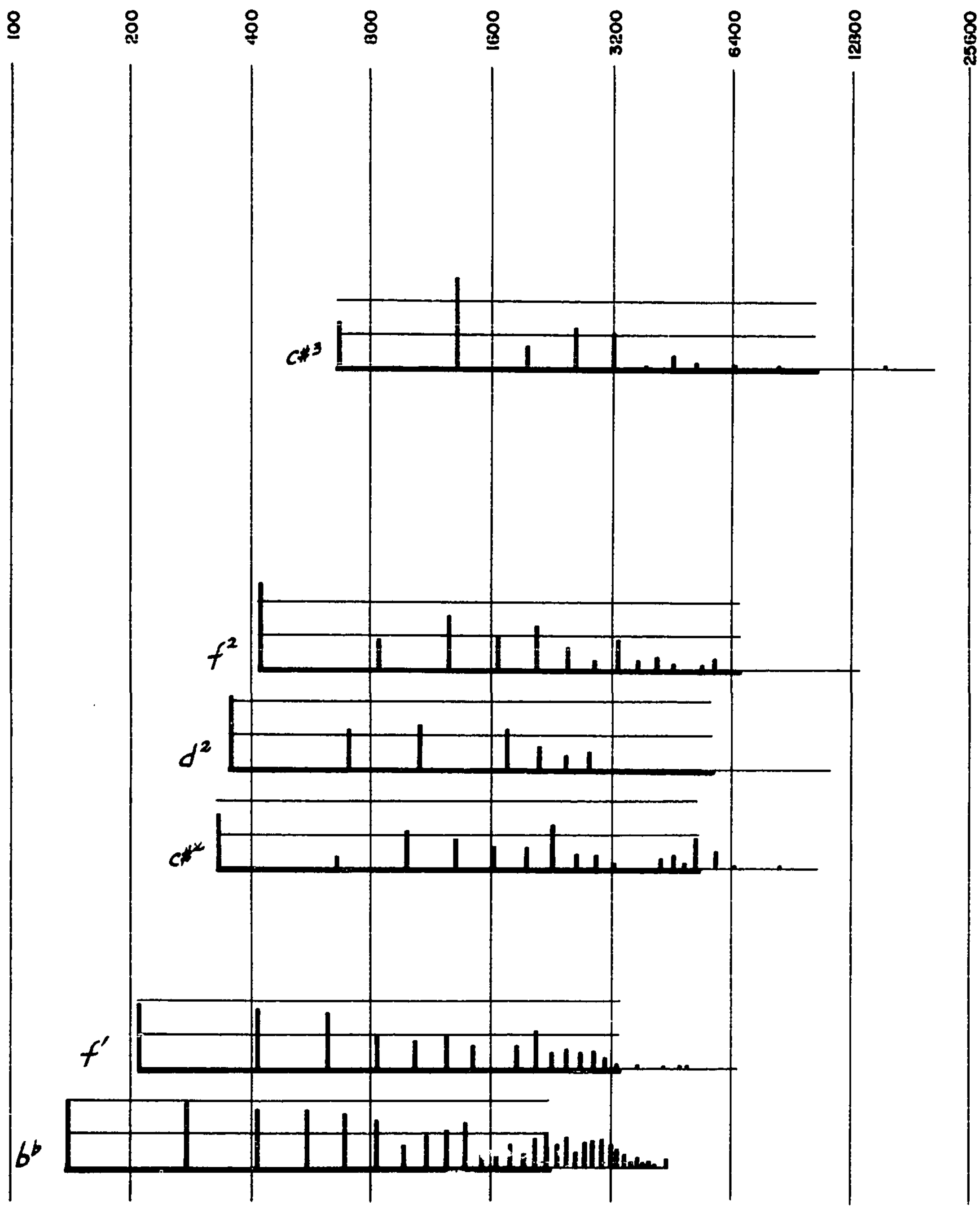
B-2



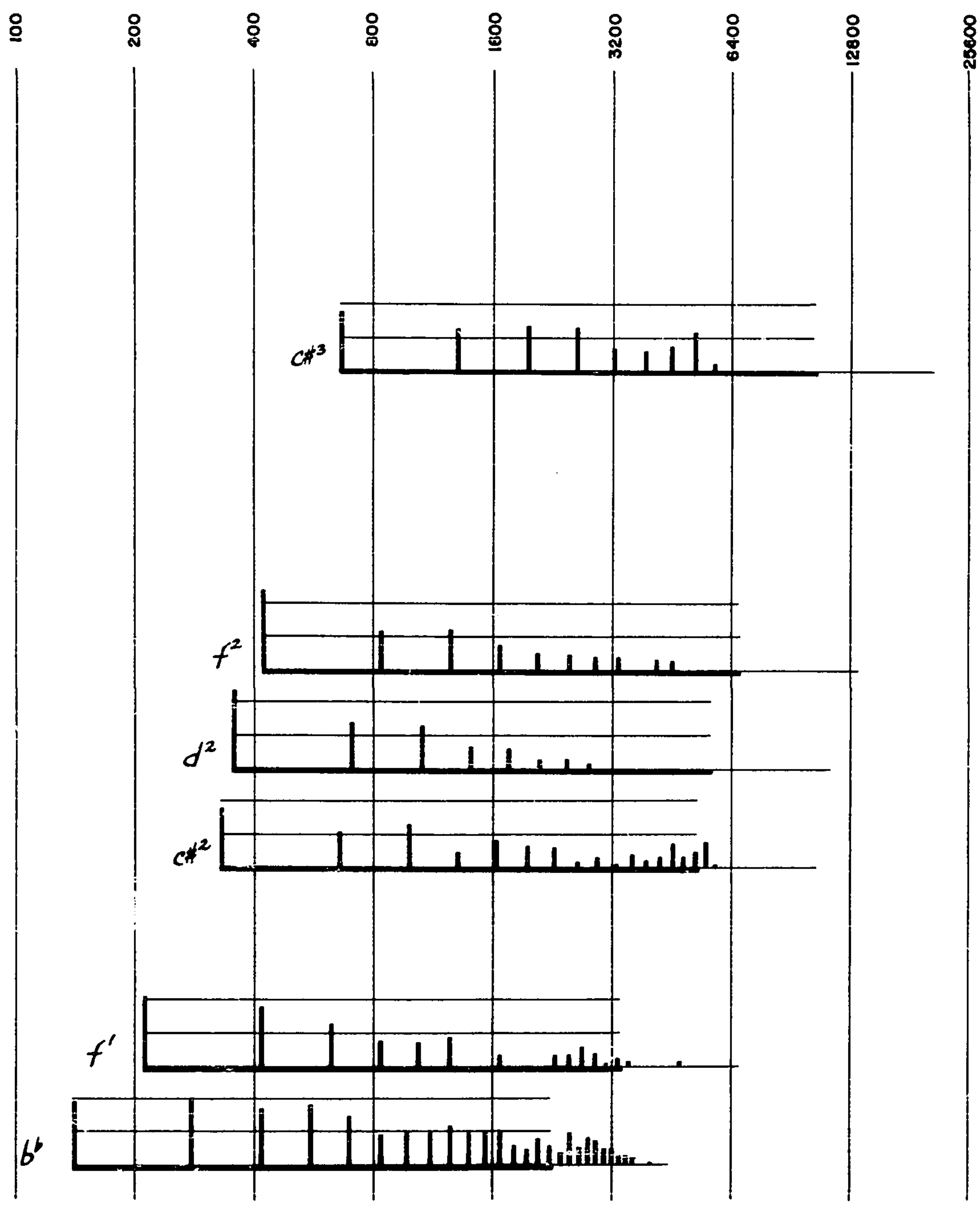
C


100
200
400
800
1600
3200
6400
12800
25600
b♭3
f3
c#3
a2
g#2
f2
d2
c#2
a'
f'
b♭

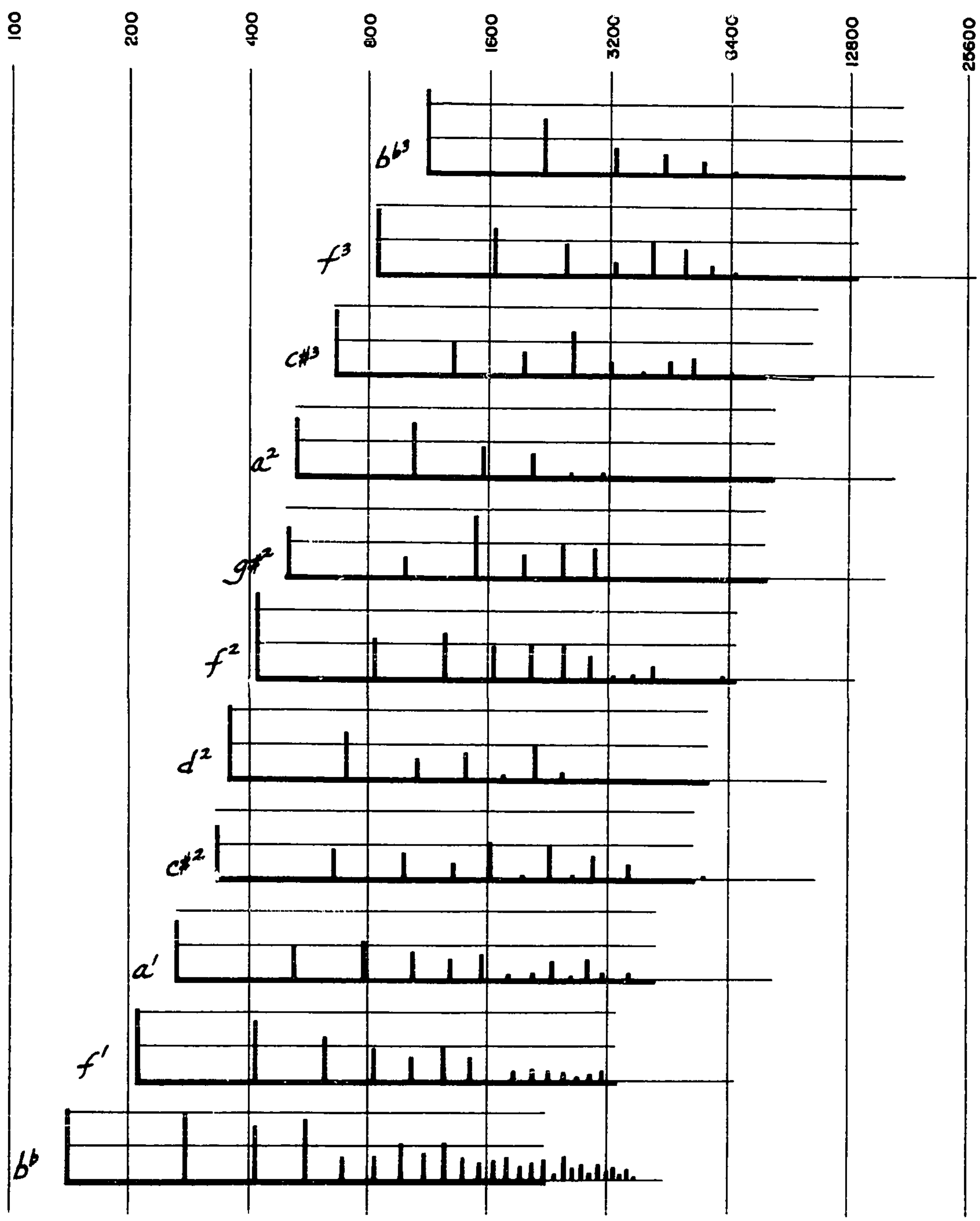
C-1



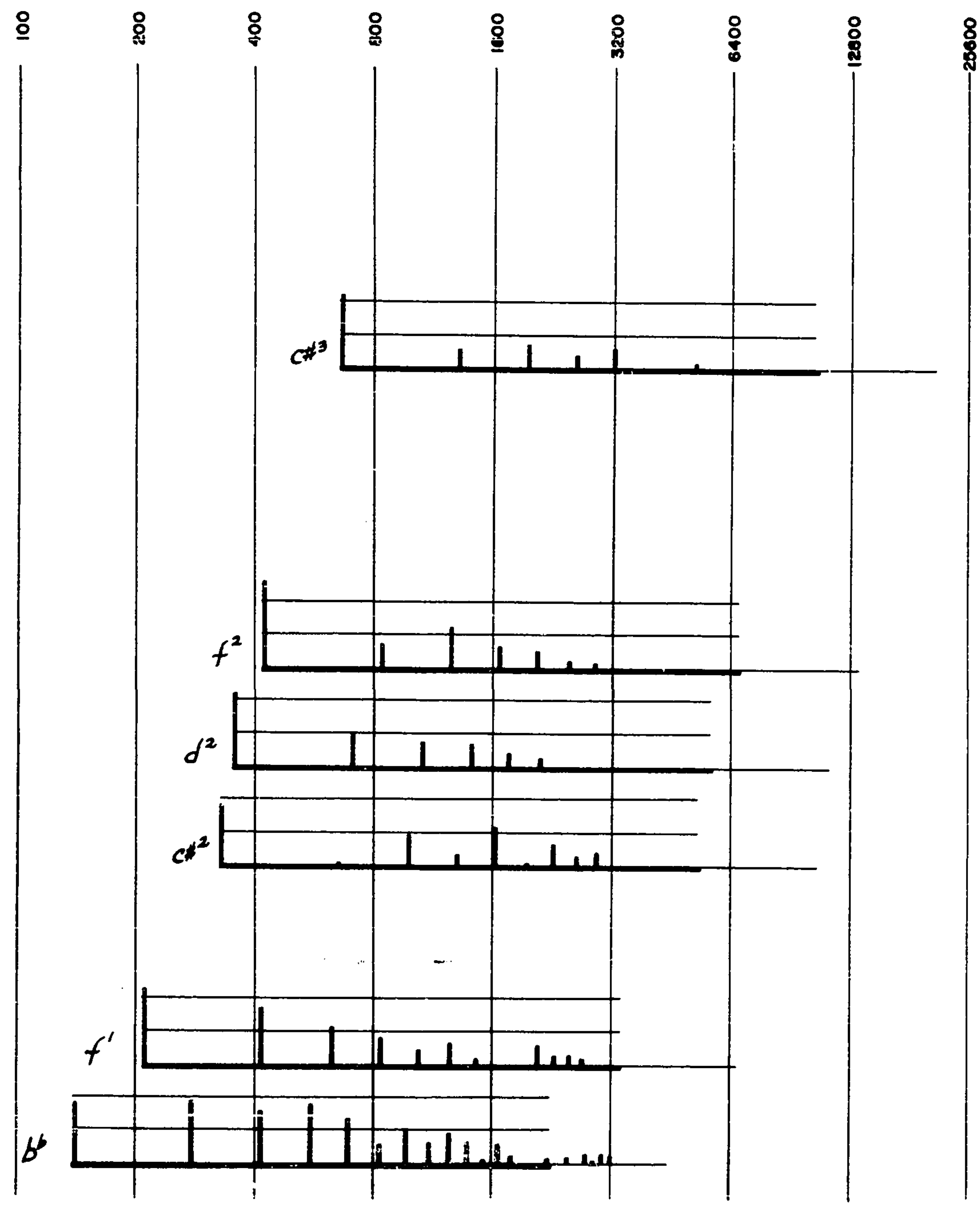
C-2



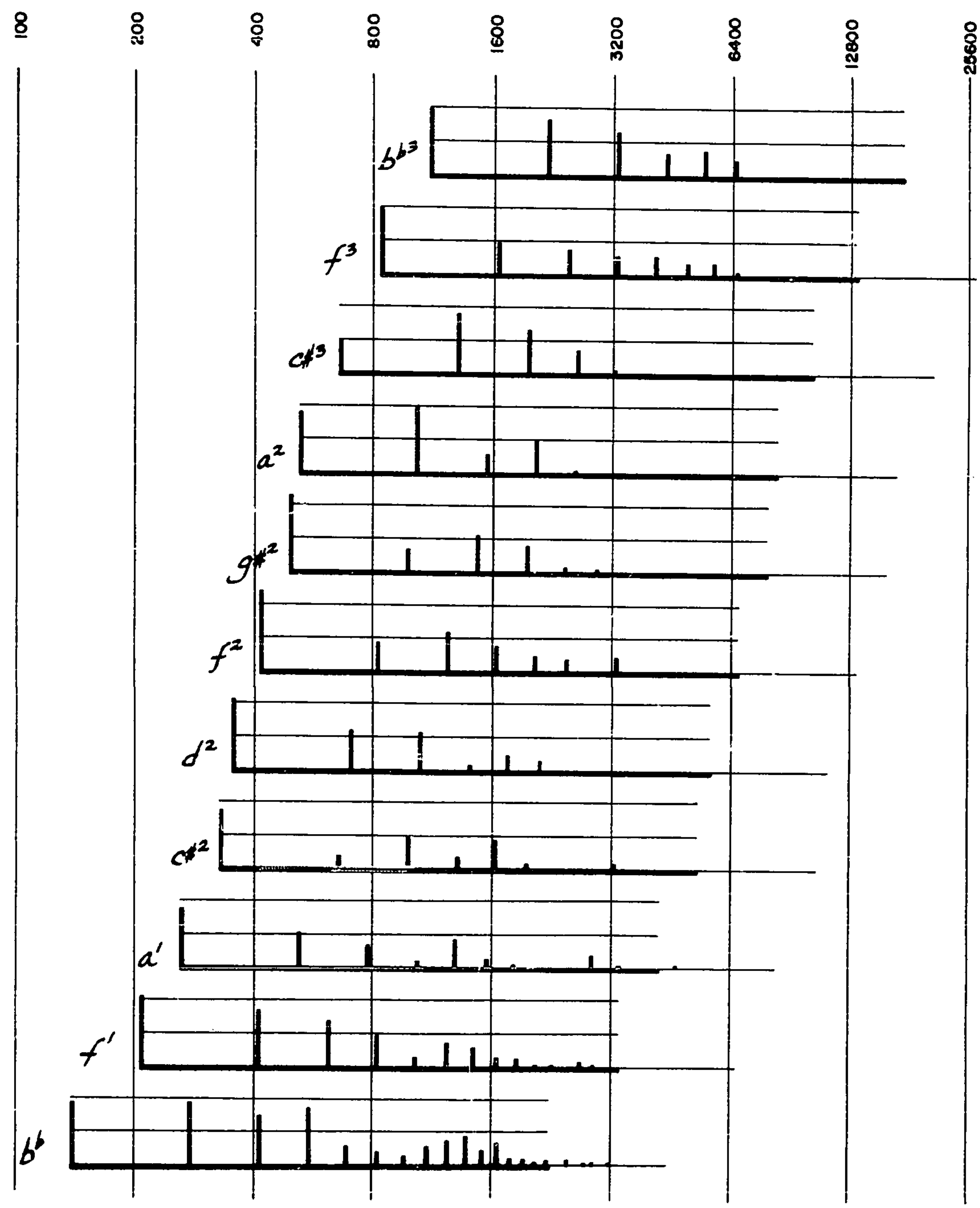
D


100
200
400
800
1600
3200
6400
12800
25600
b♭3
f3
c#3
a2
g#2
f2
d2
c#2
a1
f1
b♭

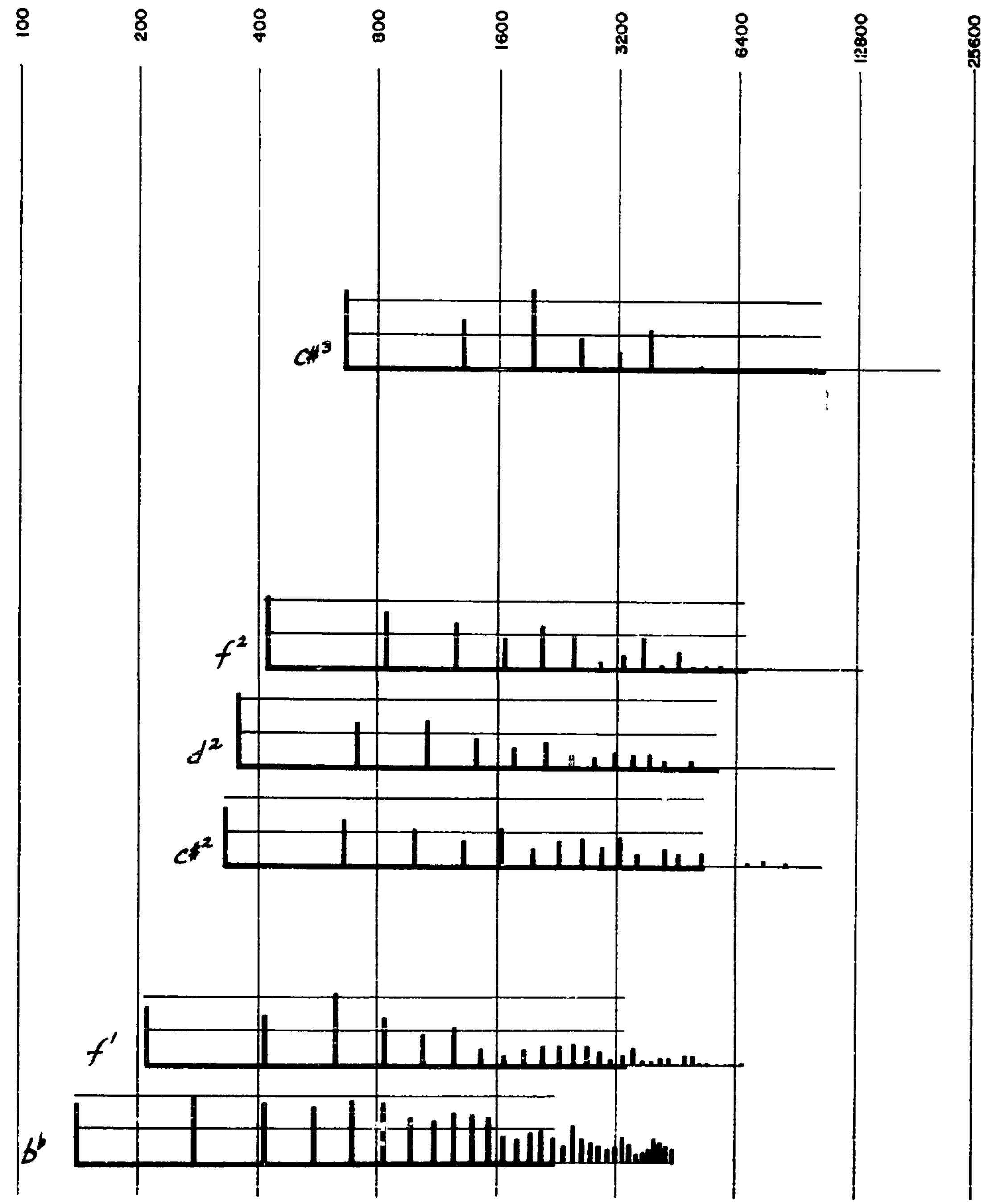
D-1



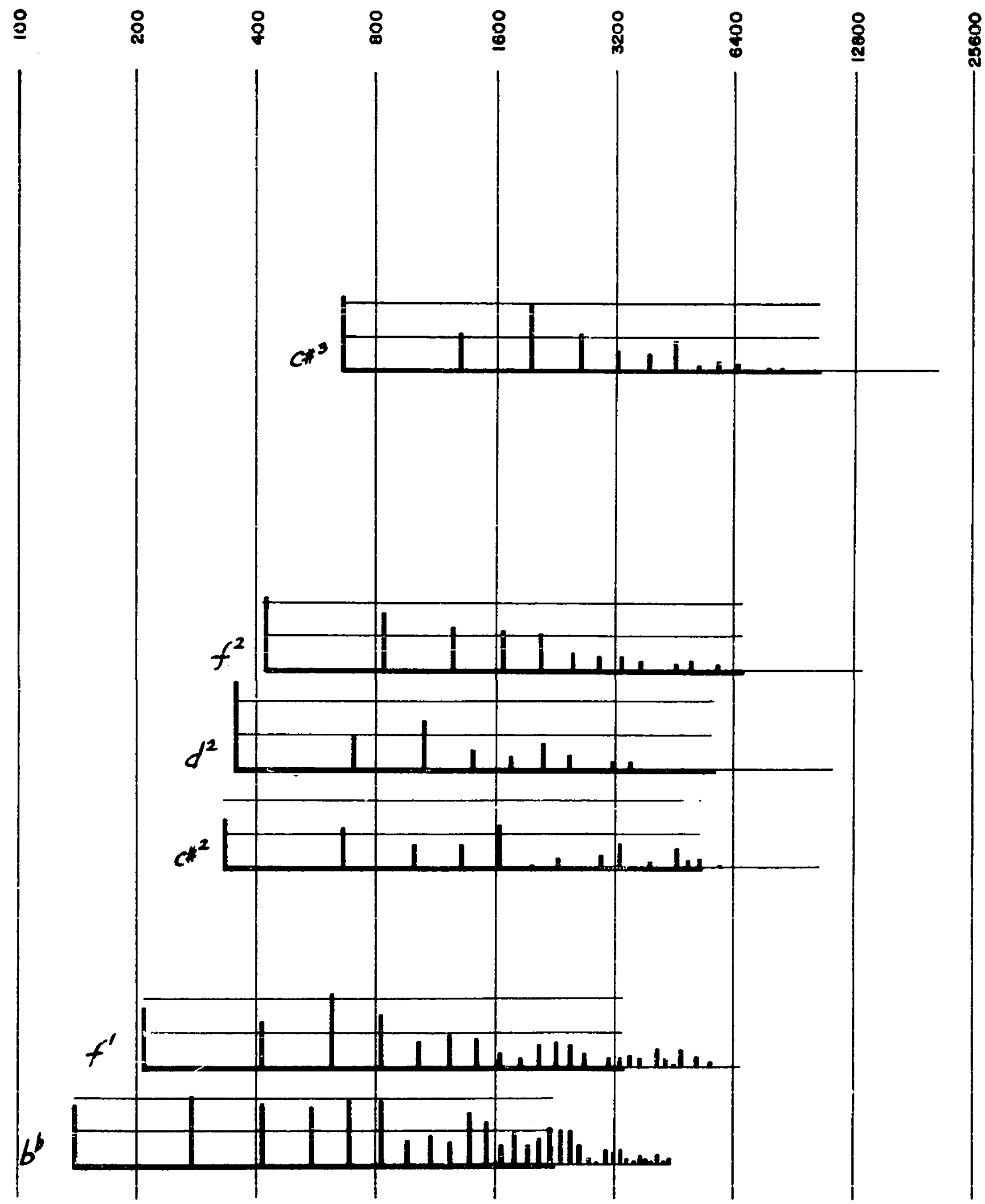
E


100
200
400
800
1600
3200
6400
12800
25600
b♭3
f3
c#3
a2
g#2
f2
d2
c#2
a′
f′
b♭

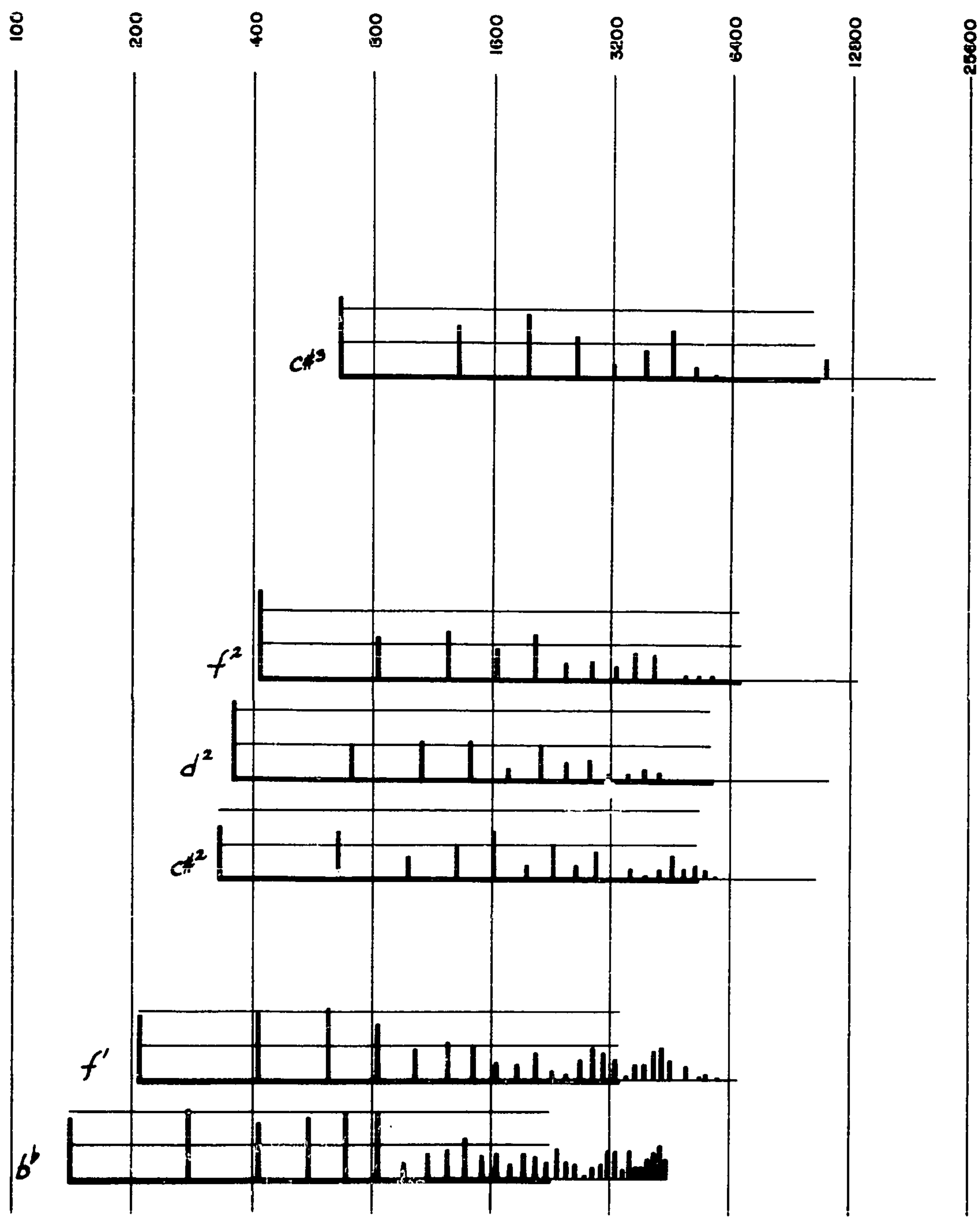
W : A



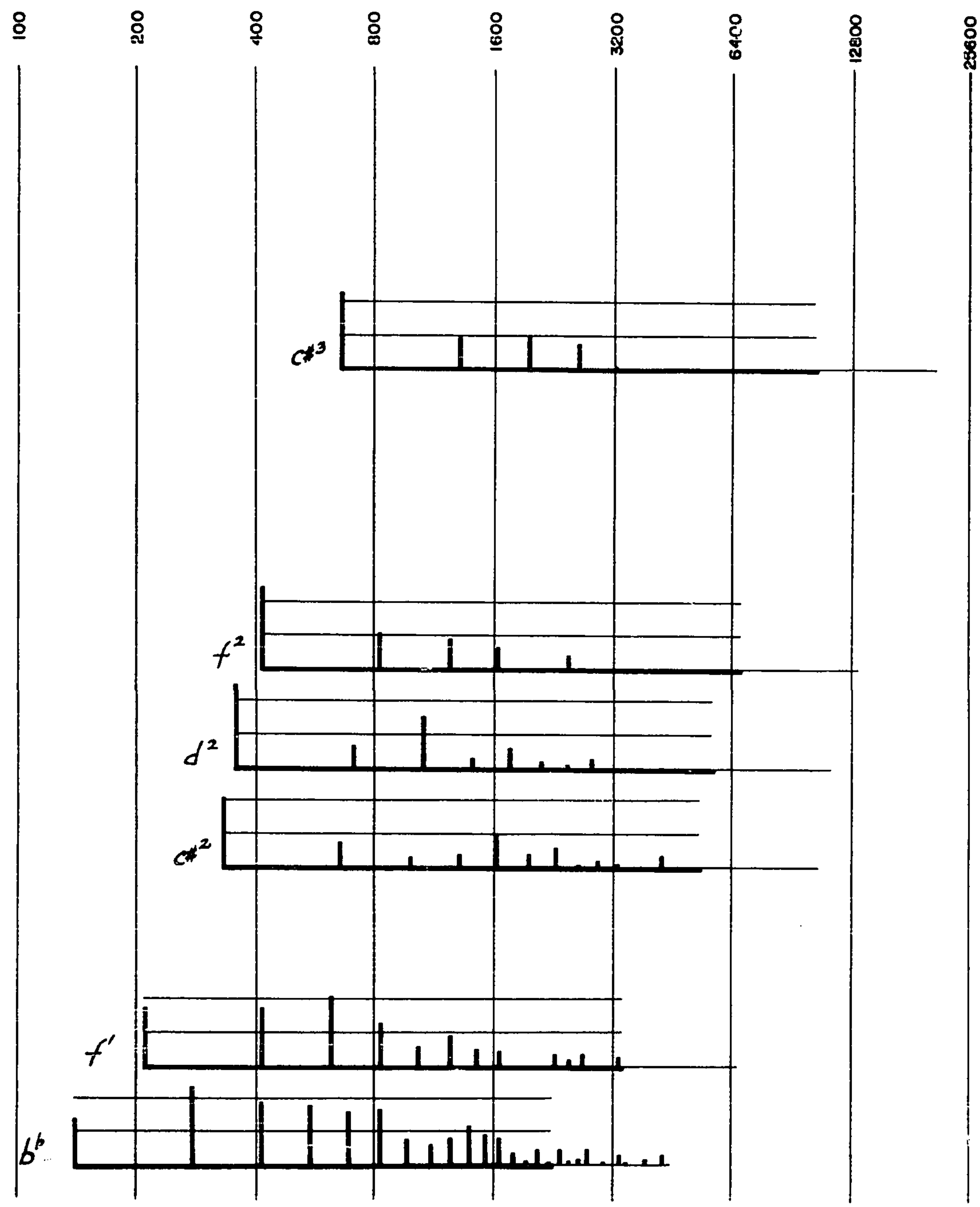
W : B



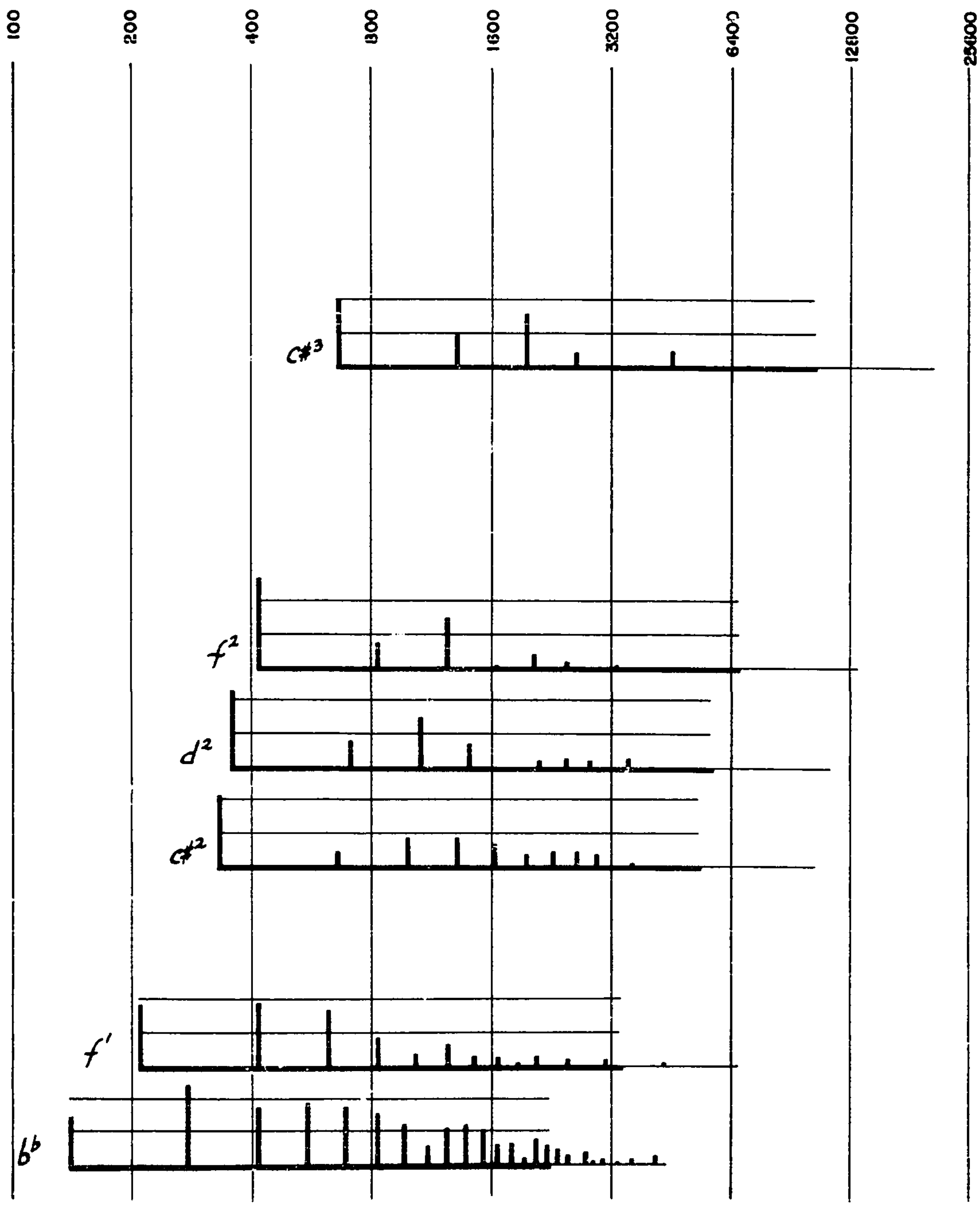
W:C



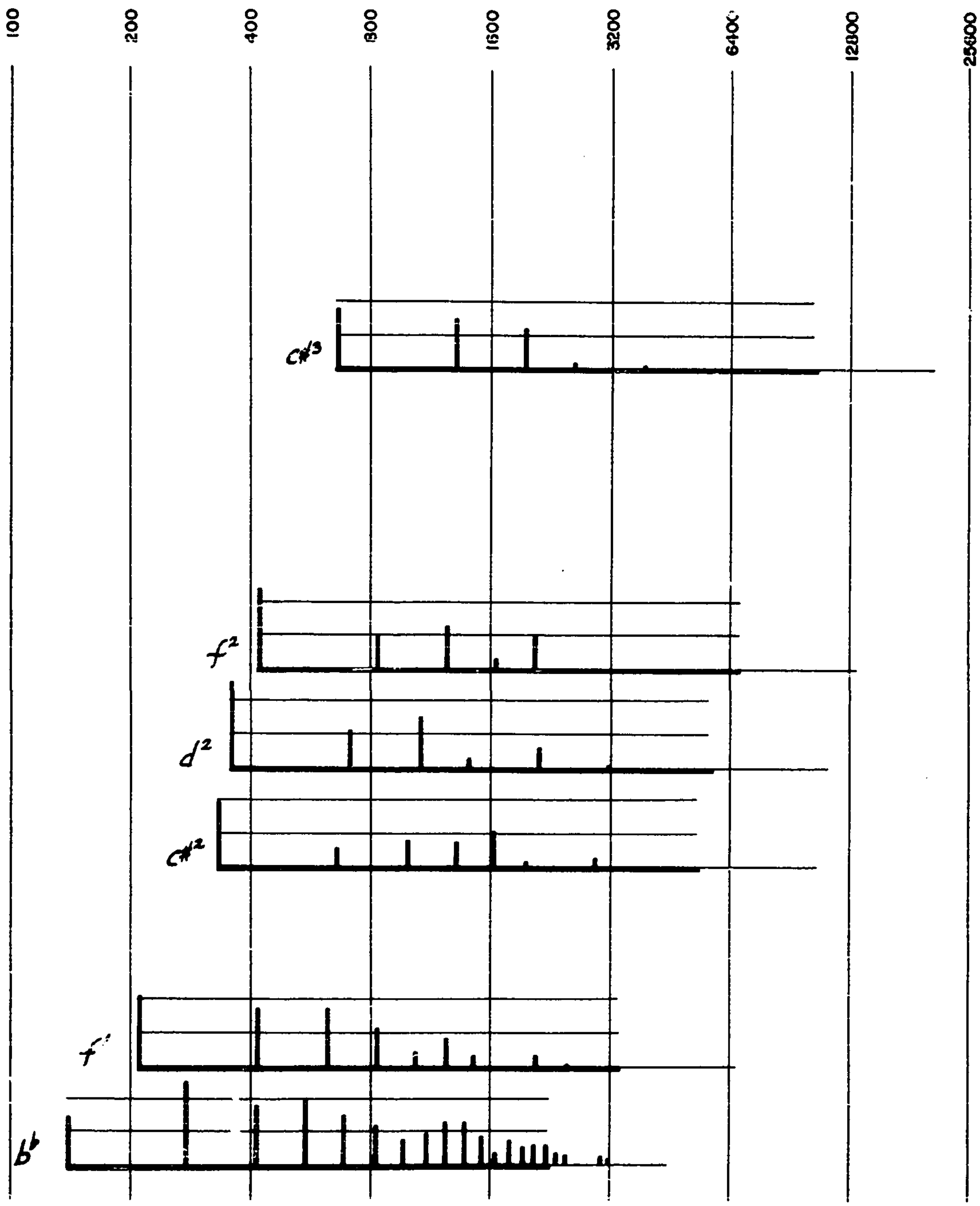
X:A



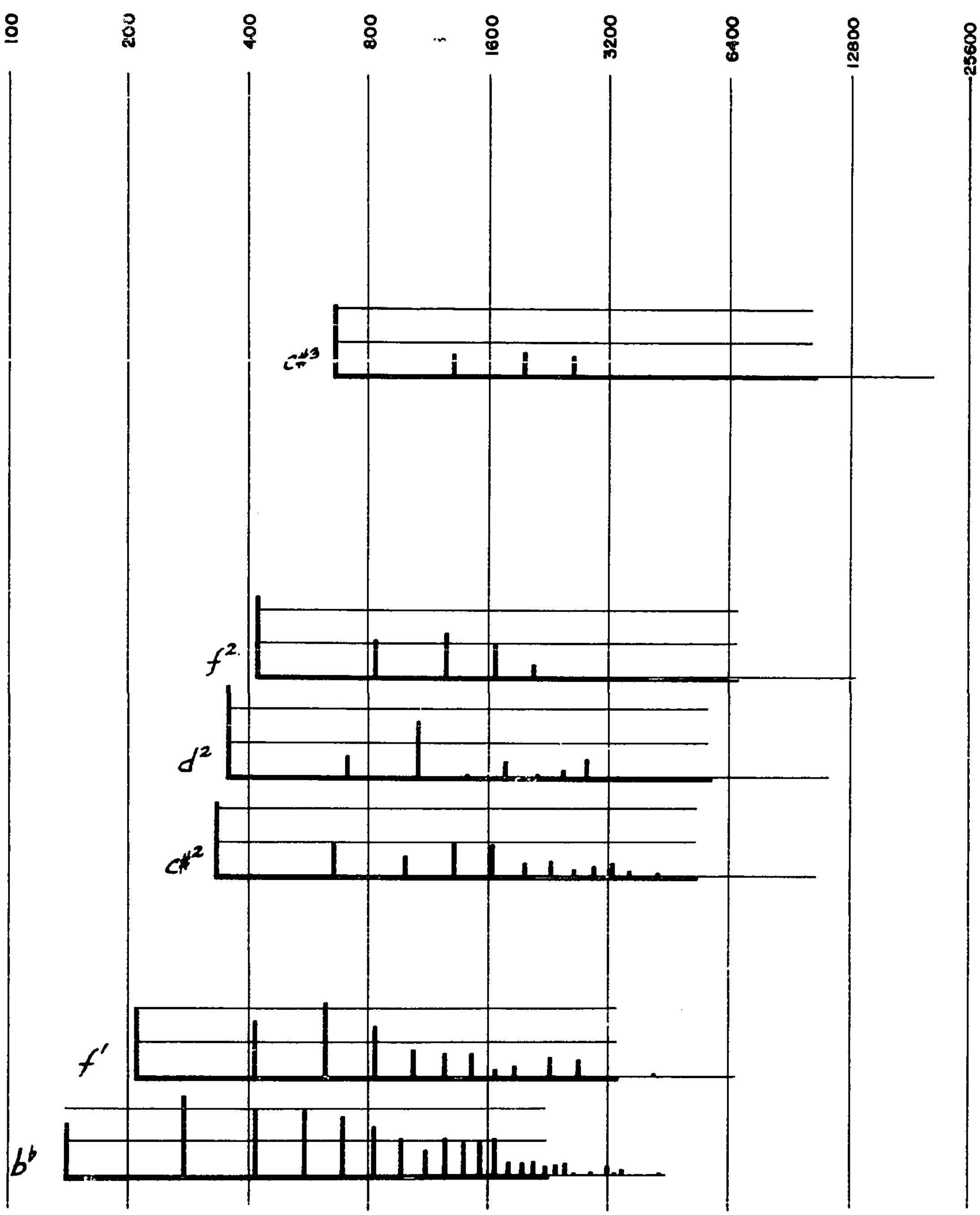
X : B



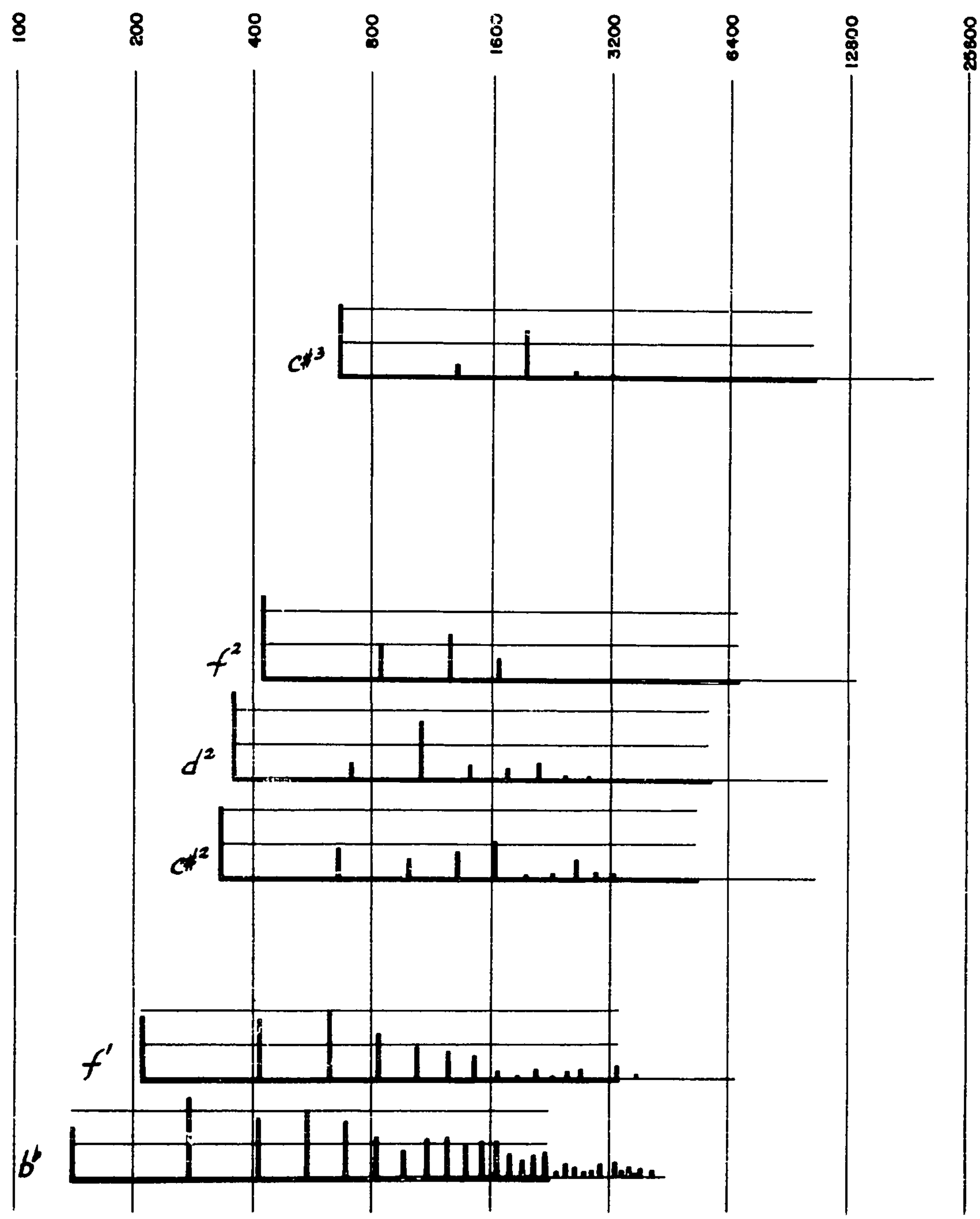
Y:A



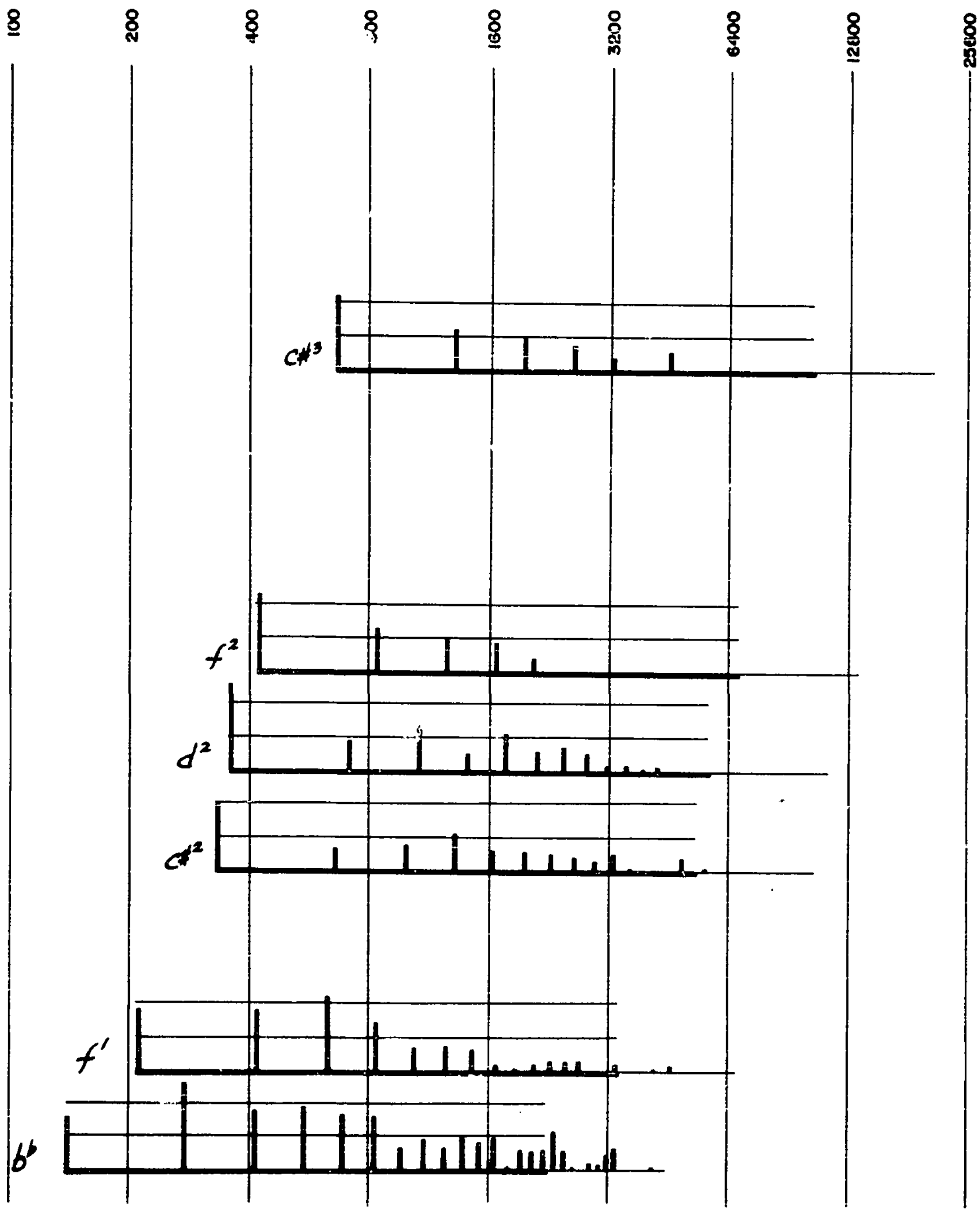
Y:B



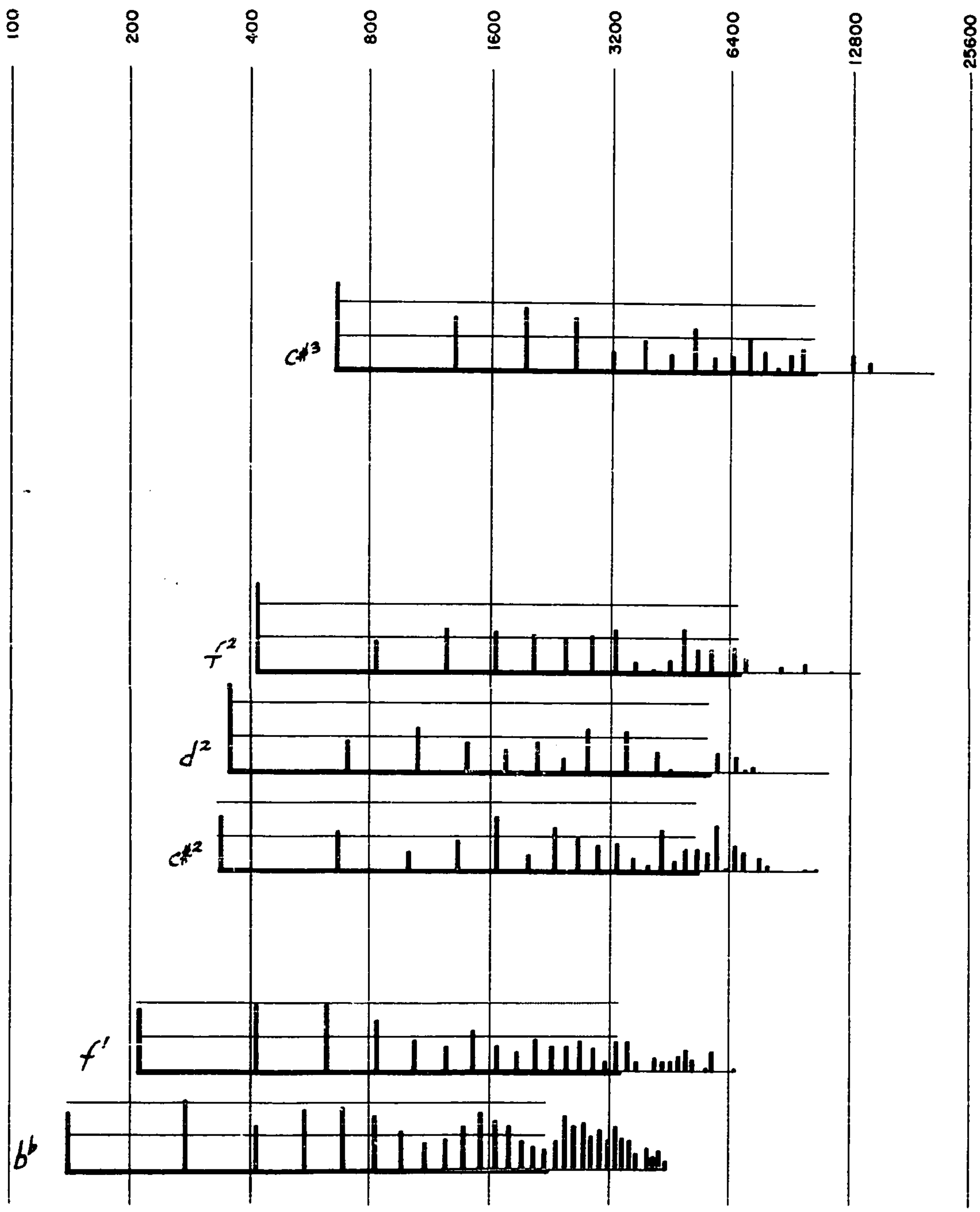
Y:C



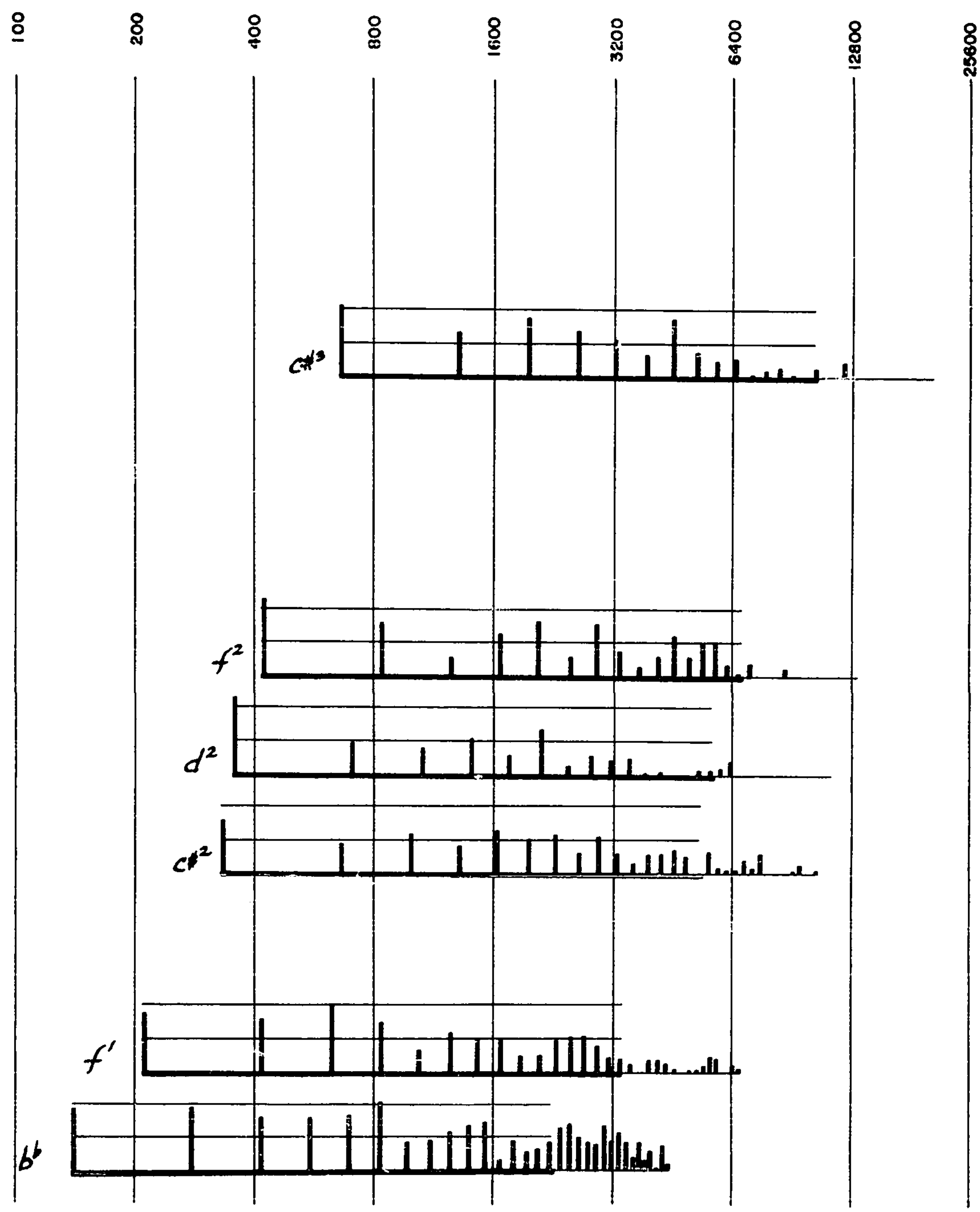
Y:D



Z : A



Z:B



APPENDIX D

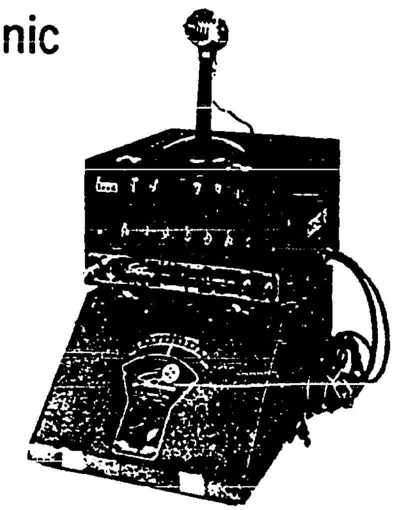
TECHNICAL DESCRIPTIONS AND SPECIFICATIONS
OF AUDIO TESTING EQUIPMENT

The following pages contain information on these specific devices:

Stroboconn.

other CONN electronic instruction aids

Stroboconn



Most accurate pitch measuring instrument available. Tuning in 84-note (7 octave) range is visible by full octaves to 1/100 of a semi-tone. Easy to operate. Unexcelled for teaching tuning of instruments, piano and organ tuning, vocal instruction, physical study of sound. Plugs into standard outlet of 110 volts, 60 cycles. Complete with carrying case.

STROBOCONN - Of all measuring and checking devices in the field of intonation, the electronic Stroboconn is generally acknowledged to be the most versatile, accurate and dependable. It provides, stroboscopically, an instantaneous, *visual* measurement of the frequency of any musical tone within a seven-octave range (C_1-B_7), a total of 84 semitones—essentially the range of a standard piano

Stroboconn (continued).

keyboard. It enables a player to identify through his *eye*, what his *ear* has heard, a precise guide to pitch. It will measure not only a single tone but, also, simultaneously, all notes of a chord, double-stopped combinations, or tones sounded by a musical ensemble. And all measurements are accurate to within 1/100th of a semitone. Far greater precision than the most reliable human ear! Stroboconn has become an indispensable aid to thousands of instrumental and vocal music teachers; a profitable "tool" for piano and organ technicians; a technical necessity in many industrial processes and research laboratories. RANGE —84 semitones; essentially the range of the standard piano keyboard. Tuning adjustable over the entire range.

ACCURACY—Within 1/100th of a semitone. (0.05%) CALIBRATION—In hundredths of a semitone. DIMENSIONS—Scanning Unit 12½ inches wide, 7½ inches high, 15¼ inches deep. Tuning Unit 12½ x 7½ x 16 inches. WEIGHT—68 pounds total. CURRENT—From standard 115-volt a.c. outlet; draws 190 watts (50-60 cycle).

The Stroboconn indicates instantly and visually whether a tone sounded is sharp, flat or in tune with respect to the equally tempered scale based on the A-440 cps standard. On the upper or scanning unit of the Stroboconn are twelve windows arranged to correspond with the black and white keys on the piano keyboard in a chromatic octave from C to B.

Neumann Model U-67 Condenser Microphone.

OPERATING INSTRUCTIONS
for the NEUMANN MODEL U 67 CONDENSER MICROPHONE

U 67 - 920-02-03

A Technical Data

U 67 Microphone

Frequency range	40 ... 16 000 cps.
Directional characteristics	Omni-directional, Cardioid, Figure 8
Sensitivity	Omni-directional: 1.1 mV/µb Cardioid: 2.0 mV/µb Figure-8: 1.4 mV/µb
Nominal terminating resistance	1000 Ω (250 Ω)
Source impedance	200 (50) Ω ± 20 % (switchable)
Total harmonic distortion ..	0.5 % up to 116 dB SPL.

NU 67(u) Power Supply

Mains voltage	117/127/220/240 Volts ± 10 % 50/60 cps
Fuses	160 mA for 117/127 Volts m.sl.bl. 80 mA for 220/240 Volts m.sl.bl.
DC output voltages	210 Volts 0.8 to 1.0 mA 6.3 Volts 200 mA

B General

The microphone capsule of the U 67 microphone is a pressure-gradient device. It is composed of two identical cardioid systems arranged back to back. By switching of the polarizing voltage these two cardioid patterns can so be combined as to produce the three directional characteristics cardioid, omni-directional, and figure-8. Selection of these patterns is accomplished by a switch located at the front of the microphone directly beneath the wire cage. The symbol of the characteristic selected appears in a window directly above the switch. Two additional switches are located at the rear of the microphone. One switch provides for a sensitivity reduction of appr. 10 dB ahead of the amplifier section

Ampex Model 351 Tape Recorder.

PERFORMANCE CHARACTERISTICS

Tape Width	¼-inch	
Tape Speed Pairs	3¾-7½ ips 7½-15 ips	
Frequency Response	*Speed (ips)*	*Response (Cycles per second)*
	3¾	±2 db 40 to 8,000
	7½	±2 db 40 to 12,000
	15	±2 db 30 to 18,000
Signal-to-Noise Ratio	*Speed (ips)*	*Peak Record Level to Unweighted Noise (db)*
	3¾	50
	7½	55
	15	Same as 7½ ips

Peak record level is that level at which the overall (input to output) total rms harmonic distortion does not exceed 3 percent when measured on a 400 cycle tone. Noise is measured after erasing a signal of peak recording level in the absence of new signal. Bias, erase and reproduce amplifier noise are included in the measurement. All frequencies between 50 and 15,000 cycles are measured.

Flutter and Wow

Speed (ips)	*Flutter and Wow (percentage rms)*
3¾	.18%
7½	.14%
15	.11%

Flutter and wow measurements include all components between 0.5 and 250 cycles. The figure quoted is for the reproduction of a relatively flutter-free test tape and is measured in accordance with American Standards Association standard number Z57.1-1954. (The alternate non-standard method of measuring flutter as described in Appendix II of the ASA standard was previously used by Ampex in determining flutter specifications.)

Recording or Reproducing Time (NAB 10½ Inch Diameter Reels, 2400 feet of tape)

	Half Track		*Two Track*	
Speed (ips)	*(hrs)*	*(min)*	*(hrs)*	*(min)*
3¾	4	16	2	8
7½	2	8	1	4
15	1	4		32

Starting Time

The tape is accelerated to full speed in less than 1/10 of a second.

Stopping Time

When operating at 15 ips, the tape moves less than two inches after the STOP button is pressed.

Reproduce Timing Accuracy

Accuracy (percentage)	*Accuracy (second)*	*Length of Recording (min)*
±.2%	±3.6	30

Ampex Model 351 Tape Recorder (continued).

Rewind Time	Approximately 1 minute for a full 2,400 foot NAB reel.
Controls	
Tape Motion	All tape motion is controlled by four pushbuttons, PLAY, STOP, FAST FORWARD and REWIND.
Record Control	A separate RECORD button on the face of the electronic assembly, when pressed, energizes the record relay which drops out when the STOP button is pressed. Selection of record channel(s) desired, is accomplished by the RECORD SELECTOR switch on the electronic assembly.
Tape Speed	Tape speed can be changed by the TAPE SPEED switch. LOW or HIGH positions are used to select drive motor windings.
Equalization	An EQUALIZATION switch on the face of the electronic assembly provides a means for selecting LOW or HIGH speed equalization appropriate to the tape speed used.
Reel Size	A REEL SIZE toggle switch on the tape transport makes possible selection of the proper tape tensioning for the NAB 10½ inch diameter reel or the EIA 5 inch and 7 inch reels.
Record Inputs	Two inputs are supplied; one for each channel. With optional plug-in preamplifiers, optional plug-in transformers of supplied dummy plugs, the inputs can accommodate microphones, balanced lines or unbalanced lines respectively. A RECORD LEVEL control is included for each channel.

Ampex Model 351 Tape Recorder (continued).

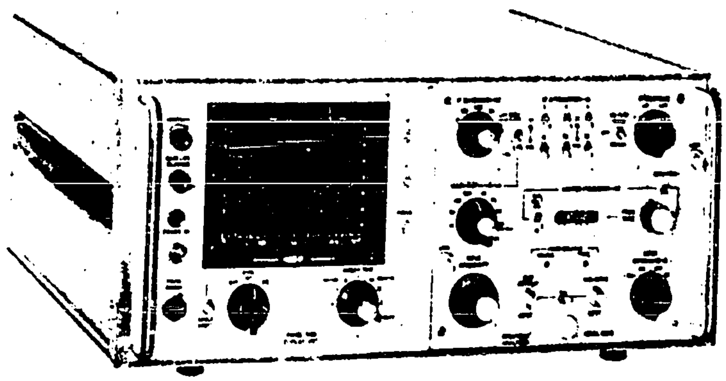
Reproduce Outputs	+4 vu ±0.5 db (Zero indication on the vu meter corresponds to +4 dbm into 600 ohms balanced or unbalanced.)
Head Housing	The erase, record, and reproduce heads are contained in a single head housing (See SECTION 7 on HEAD ASSEMBLIES).
Monitoring (aural and visual)	The signal on the tape can be monitored while the equipment is recording. Two phone jacks are available to allow monitoring the record input signal, or the output signal from the reproduce head. A switch provides a means for making direct comparison between the original program and the recorded program. Two 2½-inch vu meters are provided for level comparison and visual monitoring of each channel.
Power Requirements	Two track equipment requires 2.5 amperes at 117 volts ac, 50 or 60 cycles. When the Ampex Model 375 Precision Frequency 60 cycle amplifier is used with the equipment, power requirements are greater by 2.5 amperes.

Sony Model 600 Tape Recorder.

Technical Specifications

Power Requirement:	80 watts, 117 volts, 60 cycles
Tape Speeds:	Instantaneous selection 7½ ips or 3¾ ips (19 or 9.5 centimeters per second)
Frequency Response:	30-18,000 cps at 7½ ips ±2 db 50-15,000 cps at 7½ ips 30-13,000 cps at 3¾ ips
Signal-to-Noise Ratio: (Per Channel)	Better than 50 db
Flutter and Wow:	Less than 0.15% at 7½ ips Less than 0.20% at 3¾ ips
Harmonic Distortion:	1.5% at 0 db line output
Erase Head:	In-line (stacked) quarter track, EF18-2902
Record Head:	In-line (stacked) quarter track, RP30-2902
Playback Head:	In-line (stacked) quarter track, PP30-4202L
Bias Frequency:	Approx. 100 Kc
Level Indication:	Two VU meters (calibrated to 0 db at 12 db below saturation)
Input:	Low impedance microphone inputs—Transistorized (will accommodate any Microphone from 250 to 1K ohm impedance.) Sensitivity −72 db High impedance auxiliary inputs Sensitivity 0.15V
Output:	High impedance line outputs (max. 1.5V) Binaural monitor output
Tube Complement:	2-6AN8, 4-12AT7, 1-12BH7A, 1-6CA4
Transistors:	6-2SD64
Weight:	Approx. 48 pounds
Dimensions:	16¾"W × 18$^{3}/_{16}$"D × 10¾"H

Systron Donner Model 710B/801B Spectrum Analyzer.



DESCRIPTION

The Model 710B/801B Spectrum Analyzer is a solid state, electronically swept system which provides a display of the 10 Hz to 50 kHz frequency range on a 7 x 10 cm calibrated CRT. Increased measurement accuracies are accomplished by the use of a new Automatic Optimum Resolution Circuitry. Proper sweeptimes and I.F. bandwidths are automatically selected for any scanwidth setting. Manual selection of I.F. bandwidth and sweeptime is also available over the complete range.

The Model 710B/801B provides a tracking oscillator output signal and a choice of either logarithmic or linear frequency scan, in addition to all other features of the Model 710B/800B Spectrum Analyzer. The coherence of the tracking oscillator and the analyzer scanning signals allows accurate frequency response measurement for systems and components without the masking of peaks and nulls by harmonics, noise, and hum. This instrument is extremely versatile and easy to use for many audio measurements in-

Systron Donner Model 710B/801B Spectrum Analyzer (continued).

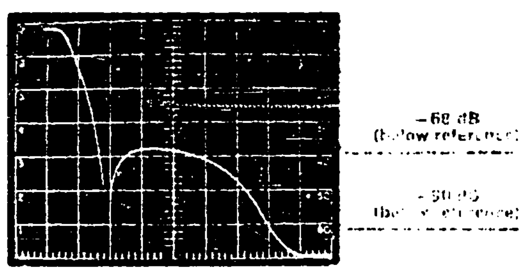
cluding frequency response, distortion, insertion loss, hum, noise, etc.

In the linear scan mode five I.F. bandwidths are available for optimum selectivity: 10 Hz, 100 Hz, 500 Hz, 1 kHz and 3 kHz. In the log scan mode the I.F. Bandwidth is continuously adjusted automatically for proper resolution.

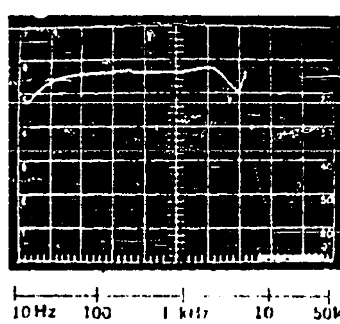
The Model 710B/801B is a portable unit, capable of operating up to 8 hours from an internal, rechargeable battery pack (optional) or can be operated from conventional AC sources.

Permanent recordings of CRT displays may be made using an optional camera adapter, or an X-Y recorder since both vertical and horizontal deflection voltages are available on the rear panel along with a "pen-lift" control output. Single Sweep and Base Line Blanking are front panel controls which ensure clarity of photographs.

The utilization and versatility of the 710B/801B can be expanded by adding other Systron-Donner 800 Series plug-ins to cover specific frequency ranges and applications.



An exploded view of high frequency region of same filter, using a linear frequency display calibrated at 1 kHz/cm and centered at 8 kHz. Vertical sensitivity is increased by 40 dB so that 60 dB line now represents 90 dB below original reference. Note the sharp, noise-free display of sidelobes and nulls, and also that the full scan log display in left photo can be restored at the flick of a switch; attenuator setting need only be changed if analyzing range is greater than 60 dB.



Log scan display of filter characteristics, showing in-band ripple and sharp cutoff at 5 kHz. Vertical display is logarithmic (10 dB/cm) with reference at the 10 dB line, indicating a filter insertion loss of 4 dB and out-of-band rejection in excess of 55 dB.

Systron Donner Model 710B/801B Spectrum Analyzer (continued).

CENTER FREQUENCY RANGE—10 Hz to 50 kHz.

CENTER FREQUENCY DIGITAL READOUT—0 to 50 kHz, 20 Hz readout resolution. 0 to 5 kHz, 2 Hz readout resolution.

CENTER FREQUENCY ACCURACY—1% ±20 Hz.

LINEAR SCAN WIDTH—6 calibrated positions ± 5%: 10 Hz/cm, 30 Hz/cm, 100 Hz/cm, 300 Hz/cm, 1 kHz/cm, 5 kHz/cm. Vernier allows adjustment between steps.

LOG SCAN WIDTH—20Hz to 50 kHz.

AMPLITUDE RESPONSE—± .5 dB 20 Hz to 30 kHz, ± 1 dB 10 Hz to 50 kHz.

LINEAR DISPLAY SENSITIVITY —5 calibrated input attenuator positions in 20-dB steps: 3μv/cm to 3mV/cm at 10k or 1 megohm input impedance; .09μv/cm to .9mV/cm at 600 ohm input impedance; and .03μv/cm to .3mV/cm at 50 ohms input impedance. Accuracy: ± 10%.

LOG DISPLAY SENSITIVITY —5 calibrated input attenuator positions in 20-dB steps: 3V to .3mV full scale for 10k or 1 megohm; .9V to .09mV full scale for 600 ohms; and .3V to .03mV full scale for 50 ohms. Accuracy: ± 2 dB.

INPUT IMPEDANCE—50, 600 ohms, 10k and 1 megohm selectable by front panel switch. (20μμf input capacity for 1 megohm position.)

INTERNAL NOISE LEVEL—(10Hz bandwidth)

Input Impedance	Maximum Noise
50 ohms	.02μV
600 ohms	.06μV
10k ohms	.2μV
1 megohm	1μV

RESOLUTION/IF BANDWIDTH—Five calibrated positions: 10 Hz, 100 Hz, 500 Hz, 1 kHz and 3 kHz ±20% with three cascaded crystal filters. AUTO position for use in Automatic Optimum Resolution, dependent upon sweeptime and scanwidth. The 10 Hz filter has a selectivity curve of less than 10:1 for a 60 db to 3 db bandwidth ratio.

I. F. bandwidth varies from 10 Hz through 500 Hz automatically as input frequency is tuned from 10 Hz to 50 kHz in the LOG SCAN mode.

IF ATTENUATOR—60 dB in 1, 3, 6, 10, and 20 dB calibrated steps with accuracy of 0.1 dB per dB. Vernier potentiometer allows smooth 6 dB adjustment.

DISPLAY DYNAMIC RANGE—

Mode	Range	Accuracy
Log	60 dB	± 2 dB
Lin	30:1	± 10%

RESIDUAL DISTORTION—Greater than 70 dB down.

SMOOTHING FILTER (VIDEO)—Three position switch: 20 ms, 200 ms and normal (OFF).

BFO OUTPUT—1.0V rms available on front panel, 600 ohm impedance.

Systron Donner Model 710B/801B Spectrum Analyzer (continued).

BFO AMPLITUDE— ± 0.3 db, 10 Hz to 50 kHz.

SWEEP TIME—Six calibrated switch positions: 3ms/cm, 10ms/cm, 30ms/cm, 100ms/cm, 300ms/cm, 1 sec/cm, 10 sec/cm. Accuracy: ±20%. Manual sweep provided with single turn potentiometer. AUTO position for use in Automatic Optimum Resolution, dependent upon I.F. bandwidth and scanwidth.

SWEEP SYNCHRONIZATION—Internal: Sweep free runs. Line: Sweep synchronized with power line frequency at any sweep time setting. External: Sweep synchronized with external signal. Single sweep: Sweep actuated by panel pushbutton.

OUTPUT SIGNALS—Vertical and horizontal signals applied to scope amplifiers available for external monitoring, 0 to +

INPUT SIGNALS—External sweep: 0 to +10V signal will deflect horizontal trace full screen. Blanking: +25V signal to cutoff CRT. External Sync: +5V signal synchronizes sweep.

CATHODE-RAY TUBE DISPLAY—7 x 10cm graticule, P7 Long Persistence Phosphor with Polaroid non-glare amber filter.

INTENSITY CONTROL—Sets intensity from cutoff to maximum brightness.

BASELINE BLANKING—Controls horizontal blanking over half vertical scale.

VERTICAL AND HORIZONTAL POSITION—Recessed front panel potentiometer allows adjustment for the horizontal and vertical position of the scope trace.

FOCUS—Recessed front panel potentiometer allows adjustment of the scope trace focus.

PEN LIFT—Connector at rear supplies relay contact closure for pen lift operations with X-Y recorders.

POWER—115/230V ±10%, 50 to 440 Hz, approx. 15W. Internal nickel cadmium battery pack (optional) provides 8 hour continuous operation without recharging. Can be energized from external dc source 13V to 25V.

SIZE—7" H x 16¾" W x 19½" D.

WEIGHT—40 lbs. (45 lbs. with battery pack).

RACK MOUNTING—Supplied with rack mounting brackets for installation in standard 19" W relay rack panel.

CONSTRUCTION—Completely RFI shielded and filtered.

ACCESSORIES AVAILABLE—Battery pack (SD Model 7101) and camera bezel adapter (SD Model 7105). See page 185 for Accessories listing.

ACCESSORIES FURNISHED—One Operation and Maintenance Handbook and three-prong power cord and rack mounting kit.

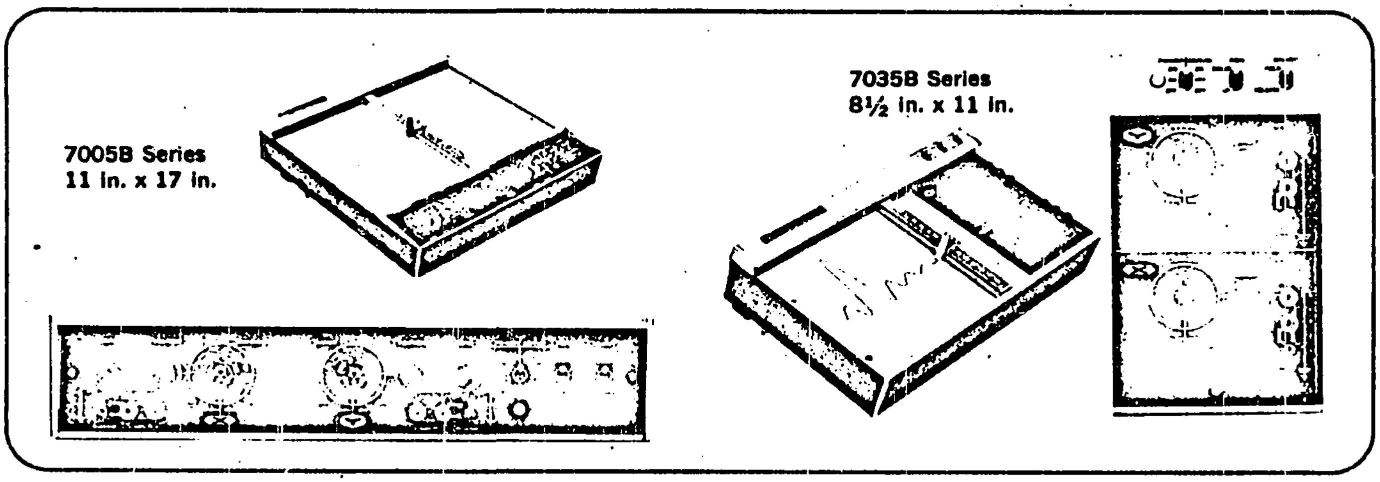
PRICE—$3,495.00.

Hewlett-Packard Model 7035B X-Y Recorder.

Models 7005B and 7035B are low cost, solid-state X-Y Recorders for general purpose applications. Each axis has an independent servo system with no interaction between channels. The recorders graph two related functions from two dc signals representing the functions. The ultra-compact design is convertible to rack mounting by addition of two wing brackets (supplied). Metric scaling and calibration are optional.

The input terminals accept either open wires or plug-type connectors. Five calibrated ranges from 1 mV/in. to 10 V/in. are provided in each axis. A variable range control permits scaling of signal for full scale deflection. Standard features include high input impedance (one megohm on all but the first two ranges), floated and guarded signal pair input, 0.2% accuracy, Autogrip electric paper holddown, electric pen lift, adjustable zero set, lockable zero and variable range controls, and rear input connector. A plug-in time base (Model 17108A) operates on either axis to provide five sweep speeds from 0.5 to 50 s/in.

Each closed-loop servo system employs a high-gain solid-state servo amplifier, Hewlett-Packard servo motor, long-life balance potentiometer, photochopper, low pass filter, guarded inputs, precision attenuator and balance circuit. Both models are designed for easy maintenance with most components mounted on a printed circuit board and accessible by removing the rear cover. Both balance potentiometers are accessible for inspection or cleaning by removing a snap-on strip.



Hewlett-Packard Model 7035B X-Y Recorder (continued).

Specifications

Performance specifications

Input ranges: English: 1, 10, 100 mV/in.; 1 and 10 V/in.; Metric: 0.4, 4, 40, 400 mV/cm and 4 V/cm. Continuous vernier between ranges.

Type of inputs: floated and guarded signal pair; rear input connector.

Input resistance:

Range	Input resistance
1 mV/in (0.4 mV/cm)	Potentiometric (essentially infinite at null)
Variable	11 kΩ
10 mV/in (4 mV/cm)	100 kΩ
Variable	100 kΩ
100 mV/in (40 mV/cm)	1 MΩ
Variable	1 MΩ
1 mV/in (400 mV/cm)	1 MΩ
Variable	1 MΩ
10 V/in (4 V/cm)	1 MΩ
Variable	1 MΩ

Input filter: >30 dB at 60 Hz; 18 dB/octave above 60 Hz.

Maximum allowable source impedance: no restrictions except on fixed 1 mV/in. (0.4 mV/cm) range. Up to 20 kΩ source impedance will not alter recorder's performance.

Accuracy: ±0.2% of full scale.

Linearity: ±0.1% of full scale.

Resettability: ±0.1% of full scale.

Zero set: zero may be set up to one full scale in any direction from zero index. Lockable zero controls.

Slewing speed: 20 in./s, 50 cm/s nominal at 115 V.

Interference rejection: conditions for the following data is line frequency with up to 1 kΩ between the negative input and guard connection point.

Range		DC (CMR)	AC (CMR)
English	Metric		
1 mV/in	0.4 mV/cm	130 dB	100 dB
10 mV/in	4 mV/cm	110 dB	80 dB
100 mV/in	40 mV/cm	90 dB	60 dB
1 V/in	400 mV/cm	70 dB	40 dB
10 V/in	4 V/cm	50 dB	20 dB

General specifications

Paper holddown: Autogrip electric paper holddown grips any chart up to size of platen.

Pen lift: electric pen lift capable of being remotely controlled.

Dimensions: 7005B: 17½" high, 17½" wide, 4-5/16" deep (445 x 445 x 110 mm). 7035B: 10-15/32" high, 17⅓" wide, 4¾" deep (266 x 445 x 121 mm).

Weight: net, 18 lb (8 kg); shipping, 24 lb (10,9 kg).

Power: 115 or 230 V ±10%, 50 to 60 Hz, approximately 45 VA.

Time base accessory: Model 17108A self-contained external time base has five sweep speeds. Price $ 175

Price:

Model 7005B—11 in. x 17 in. Chart Size $1235

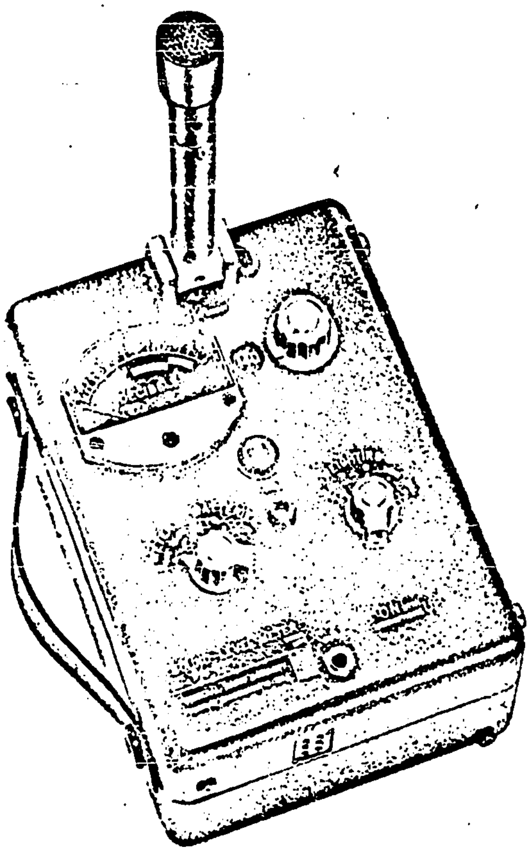
Model 7035B—8½ in. x 11 in. Chart Size $ 985

Options:

01. Metric calibration N/C

03. Retransmitting potentiometer on X-axis 5 kΩ ±3% $ 75

General Radio Model 1551-C Sound-Level Meter.



DESCRIPTION: The Type 1551-C Sound-Level Meter consists of an omnidirectional microphone, a calibrated attenuator, an amplifier, standard weighting networks, and an indicating meter. The complete instrument, including batteries, is mounted in an aluminum case. The microphone can be used in several positions and, when not in use, folds down into a storage position, automatically disconnecting batteries. An ac power-supply unit is available.

SPECIFICATIONS

Sound-Level Range: From 24 to 150 dB (re 0.0002 μbar).

Frequency Characteristics: Four response characteristics, A, B, C, or 20-kc, as selected by a panel switch. The A-, B-, and C-weighting positions are in accordance with ASA S1.4–1961 and IEC Publication 123, 1961. Frequency response for the 20-kc position is flat from 20 c/s to 20 kc/s, so that complete use can be made of very wide-band microphones such as the Type 1551-P1 Condenser Microphone Systems.

Microphone: Highly stable ceramic type. Accessory condenser microphone is available. (See page 19.)

General Radio Model 1551-C Sound-Level Meter (continued).

Sound-Level Indication: Sound level is indicated by the sum of the meter and attenuator readings. The clearly marked, open-scale meter covers a span of 16 dB with calibration from −6 to +10 dB. The attenuator is calibrated in 10-dB steps from 30 to 140 dB above 0.0002 μbar.

Output: 1.4 V behind 7000 Ω (panel meter at full scale). The output can be used to drive analyzers, recorders, oscilloscopes, and headphones. Harmonic distortion (panel meter at full scale) less than 1%.

Input Impedance: 25 MΩ in parallel with 50 pF.

Meter: Rms response, and fast and slow meter speeds in accordance with ASA S1.4-1961 and IEC R123, 1961.

Calibration: Built-in calibration circuit standardizes the sensitivity of the electrical circuits within ±1 dB at 400 c/s, as specified in ASA standards. The TYPE 1552-B Sound-Level Calibrator (page 21) is available for making periodic acoustical checks on the over-all calibration, including microphone. Microphone can be accurately calibrated with the TYPE 1559-B Microphone Reciprocity Calibrator (page 22), which can also be used for over-all acoustical checks.

Environmental Effects:

Temperature and Humidity: Microphone is not damaged at temperatures from −30 to +95°C and relative humidities from 0 to 100% When standardized by its internal calibration system or a TYPE 1552-B Sound Level Calibrator, the instrument will operate within catalog specifications (for panel-meter indications above 0 dB) over the temperature range of 0 to 60°C and the relative humidity range of 0 to 90%.

Magnetic Fields: When exposed to a 60-cycle, 1-oersted (80 A/m) field, the sound-level meter will indicate 60 dB (C weighting) when oriented for maximum sensitivity to the magnetic field.

Electrostatic Fields: Aluminum case provides sufficient shielding, so that normally encountered electrostatic fields have no effect.

Vibration: Case is fitted with soft rubber feet and amplifier is resiliently mounted for vibration isolation. When the instrument is set on its feet on a shake table and vibrated at 10 mils p-to-p displacement over the frequency range of 10 c/s to 55 c/s, the unwanted signals generated do not exceed an equivalent C-weighted sound-pressure level of 45 dB when motion is vertical, 60 dB when motion is lengthwise, or 40 dB when motion is sidewise.

Power Supply: Two 1½-V size D flashlight cells and one 67½-V battery (Burgess XX45 or equivalent) are supplied. An ac power supply, the TYPE 1262-B, is available.

Accessories Supplied: Telephone plug.

Accessories Available: TYPE 1551-P2 Leather Case (permits operation of the instrument without removal from the case). TYPE 1560-P95 Adaptor Cable, for connecting output to TYPE 1521-B Graphic Level Recorder. For other accessories, including analyzers, see pages 17 to 34.

Mechanical Data: Aluminum cabinet, finished in gray crackle.

Width		*Height*		*Depth*		*Net Weight**		*Shipping Weight**	
in	*mm*	*in*	*mm*	*in*	*mm*	*lb*	*kg*	*lb*	*kg*
7¼	185	9¼	235	6⅛	160	7¾	3.6	16	7.5

* With batteries (add 2 pounds for leather case).

For a more detailed description, see *General Radio Experimenter*, August 1961.

APPENDIX E

ENVIRONMENTAL CONDITIONS DURING TESTS

	Date	Time	Temp.	Humidity	Air Pressure
Pitch measurement and subjective analysis					
Subject 1 -	5-24-71	8 P.M.	74°	55%	29.65" falling
2 -	5-18-71	12 Noon	77°	45%	29.85" falling
3 -	5-17-71	8 P.M.	72°	34%	29.90" steady
4 -	5-17-71	11 A.M.	78°	32%	29.90" steady
5 -	5-19-71	8 P.M.	78°	45%	29.85" falling
6 -	5-24-71	10 A.M.	70°	35%	29.85" falling
7 -	5-23-71	2 P.M.	72°	33%	30.10" rising
8 -	5-25-71	9 A.M.	70°	50%	29.53" steady
Author -	5-26-71	8 P.M.	72°	35%	30.40" steady
Recording of test tones					
	5-28-71	9 A.M.	70°	41%	29.85" steady
Carrying power experiment					
	6-10-71	7 P.M.	70°	58%	30.25" steady

Fredonia is located 765 feet above sea level.

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