AFFDL-TR-66-8

DESIGN AND PERFORMANCE OF A 15 KW WIDE BAND ACOUSTIC FACILITY

KEITH M. HANKEL

JOHN P. HENDERSON

Distribution of this document is unlimited.

FOREWORD

This report was prepared by the Aero-Acoustics Branch, Vehicle Dynamics Division, Air Force Flight Dynamics Laboratory. Two phases of work are covered by this report. The first phase included the design and fabrication of the test facility and was performed under Project 1309, "Flight Vehicle Environmental Investigations," Task No. 130901, "Acoustical Environmental Investigations," Messrs. K. M. Hankel and J. P. Henderson, Project Engineers. The second phase, which included the acquisition of performance data and the development of techniques for improving the spectrum, was performed under Project No. 4437, "High Intensity Sound Environment Simulation," Task No. 443705, "Development of Noise Sources," Mr. K. M. Hankel, Project Engineer. The work was administered by the Air Force Flight Dynamics Laboratory, Research and Technology Division, Air Force Systems Command, Wright-Patterson Air Force Base, Ohio.

This report covers work conducted from November 1960 to June 1964. The manuscript was released by the authors in November 1965 for publication as an RTD Technical Report.

The authors express their appreciation to Dr. H. E. von Gierke and Mr. J. N. Cole for their comments and cooperation during the design and evaluation of the siren, and to Messrs. C. A. Golueke, D. C. Kennard, and A. W. Kolb for their support and encouragement.

This technical report has been reviewed and is approved.

H. A. Magrath

H. A. MAGRATH
Chief, Vehicle Dynamics Division
Air Force Flight Dynamics Laboratory

ABSTRACT

Details of the design and performance of a wide band, high intensity, acoustic test facility are presented. The wide band siren, horn network, sound isolation room, noise measurement and analysis instrumentation, input power requirements, and measured performance characteristics of the facility are described. The problem of the presence of several discrete frequency peaks in the spectrum of the original siren configuration is discussed along with techniques which were investigated to improve the spectrum. Frequency modulation of the rotor speeds is shown to result in a relatively smooth, continuous randon spectrum. The limited spectrum shaping capabilities of the siren are discussed. Recommendations are made for improvements that could be incorporated into future designs of sirens of this type.

TABLE OF CONTENTS

SECTION PAGE

TABLE OF CONTENTS (Continued)

ILLUSTRATIONS

ILLUSTRATIONS (Continued)

SECTION I

INTRODUCTION

The intense wide band acoustic noise associated with rocket and turbojet engine operation has long been recognized as an environment which can be detrimental to structures, equipment, and personnel. Many attempts have been made to simulate this noise in the laboratory both for research and ad hoc proof testing of design configurations. Several types of noise generators have been used in these acoustic test facilities such as loudspeakers, discrete frequency sirens, electromagnetically operated air valves, air jets, and wide band sirens (References 1 and 2). One of the most promising techniques developed for economical and realistic simulation of high intensity acoustic noise is the wide band siren invented and initially developed by von Gierke and Cole (Reference 3). This report discusses the design and performance of an acoustic test facility which utilizes a wide band siren of this type. It differs in many respects, however, from the original configurations built and tested by Cole, et al. (References 4, 5 and 6).

The facility was designed, fabricated, and further developed in the Air Force Flight Dynamics Laboratory, Wright-Patterson Air Force Base, Ohio. It is the purpose of this report to present some of the problems that were encountered during the development of this facility, particularly for the siren, and their solutions with the hope that it will aid in the future development of this type of noise source. Figure 1 shows the facility which was developed under this program. Details pertaining to the general facility are found in the Appendix.

SECTION II

DESIGN AND DEVELOPMENT OF A WIDE BAND SIREN

DESIGN APPROACH

The noise generator utilizes the basic operating principles of nonperiodic mechanical modulation of the mass flow of air through a nozzle (References 4, 5 and 6).

The wide band siren was designed and developed with the following objectives in mind:

1. Obtain a versatile and dependable acoustic environmental test tool;

2. Obtain a test tool which would have a greater acoustic power output and which would be more efficient than the original models;

3. Utilize an existing air supply; and

4. Obtain a test tool that would be relatively inexpensive.

To ensure versatility and dependability, the siren and horns were to be constructed in such a manner that they would be semiportable. This semiportable facility was to be an acoustic environmental test tool that could be used to simulate present day jet and rocket noise, and would have adequate acoustic power to meet any estimated future test requirements for equipment and subsystems, and would be mechanically sound. Ground emphasis was placed on designing facility components that would have long service life and require infrequent teardown for inspection and lubrication. Special attention was given to the material and shape of the siren rotors since some similar type sirens in the past have had short lives due to rotor fatigue problems.

To achieve the objective of greater acoustic power and efficiency, the approach adopted was mainly to increase the mechanical and electrical power into the system and reduce the air losses throughout the system. In addition it was desirable to have some capability for spectrum shaping and to have a greater range and better control of rotor speeds.

The design was to combine compactness with versatility into a semiportable facility that could be easily adapted to a limited number of combined environments.

SIREN DESIGN

The siren by itself, is relatively small and compact (References 7 and 8). The maximum diameter, including the housing, is 12 inches (305 mm); the length also is approximately 12 inches (305 mm). Figure 2 shows a close-up of the siren without the housing; a cross sectional view is shown in Figure 3. The four rotors revolve around a single fixed shaft with a clearance between the rotors of approximately 0.030 inch (0.7 mm). The two outer rotors rotate over the two inner rotors. Each is driven independently through a V-belt by a 2-horsepower DC motor. Speed and direction of each rotor are controlled from a remotely located control booth. The rotors are enclosed in an annular-shaped cast aluminum case in which a close control was kept on the gap between case and rotor, thereby reducing the air losses.

The siren with the first horn section is shown in Figure 4. The air supplied by the compressors flows (from right to left in Figure 4) through the wall of the room via the hoses, then through the inlet tubes to the four nozzles that are mounted in the rotor case. The air flow is modulated by the four irregularly shaped rotors located in the rotor case. (See Figure 5.) The air exhausts from the rotor case via the four small horns which make up the first horn section.

ROTOR DESIGN

The design of the rotors received great emphasis. As stated earlier, rotor fatigue was a problem in previous siren designs. Several techniques were used in an effort to eliminate this problem: (1) rotor material was chosen to combine the characteristics of a high endurance limit, corrosion resistance, and good machinability; (2) stress concentrations resulting from sharp corners, tool marks, etc., were eliminated as much as possible, and (3) rotor shapes were designed to eliminate severely stressed portions, such as the rotor rim.

The rotors were made of Armco 17-4 PH heat-treatable, stainless steel which in its heat-treated state, has several desirable properties. It has an endurance limit of approximately 90,000 psi (63.3 kg/mm^2), a yield strength of approximately 185,000 psi (130 kg/mm^2) an ultimate strength of around 200,000 psi (140 kg/mm^2), and is still machinable to the extent that it can be turned, milled, or ground. The rotors were fabricated by first forging their rough shape, then heat-treating the steel, and finally machining the rotors to the final dimensions.

The various shapes of the rotors are shown in Figure 6. The preliminary design included a rim on the outside periphery of each rotor. However, since each rotor was designed to be 80 to 85 percent open, the resulting span along with the contemplated high rotor speeds created a rim deflection far in excess of that which could be tolerated. For this reason the rims were removed. Figure 6 shows that each corner of each rotor has a radius. The small radii were used initially to reduce stress concentrations in each corner. In addition, special attention was paid to the elimination of tool marks and scratches that might act as stress raisers. Stress calculations based on the assumption of a biaxial stress condition resulting from the combined effects of radial forces, hoop stresses, bending stresses induced by the fluctuation of the air pressure load, and typical stress concentration factors showed stresses well below the endurance limit of the material. The larger radii and the cutout that can be seen on the blades in Figure 6 were necessary in order to dynamically balance the rotors. A rough balance of each rotor was obtained by first calculating and then milling out the necessary material on the downstream side of some of the rotors. The fine balance was achieved by checking on a Gisholt balancing machine, increasing the size of the radii on the blades and removing stock from the rotor periphery, where necessary.

The number and position of the blades on each rotor were chosen in a somewhat arbitrary manner. The main criteria in the design of the rotor blades were: (1) to be most effective they should be large enough to completely close off an air port; (2) they should vary in size; and (3) the blades of a given rotor should be a different distance apart than those of any other rotor. The blade sizes and distances were varied with the expectation that it would help to randomize the output of the siren.

ROTOR DRIVE AND CONTROL

Each rotor is driven independently by a 2-horsepower DC motor through a V-belt. The motors are mounted below and on an angle of 45 degrees as shown in Figure 7. The rotor speeds are variable and can be controlled from as low as 625 rpm to as high as 5000 rpm. The motors are reversible and hence the rotors can all be rotated in either the same direction or counterrotated. The speed and direction of each rotor is monitored with tachometers and controlled from the control booth mentioned previously. The tachometers are powered by AC tach-generators that are mounted on each motor. Each motor receives its power from a 300-volt DC rectifier which, in turn, receives its power from a 440-volt AC single phase source.

BEARINGS AND LUBRICATION

The ball bearings used in the siren are precision (AEBC-5 and 7) angular-contact bearings loaded with a light preload. The lubricant used in the bearings is an aircraft and instrument grease-type bearing lubricant, conforming to MIL-G-3278A. Four different-sized bearings were used in the siren as shown in the cross-sectional view in Figure 3.

The smallest bearings are located near both ends of the fixed shaft. The second smallest bearings, also on the shaft, were duplexed in a manner to resist pulsating loads from the air flow. No problems were expected with these bearings because of their small size and the anticipated relatively low rotor speeds. For this reason no provision was made for lubricating the small bearings other than a complete teardown of the siren.

The two larger-sized bearings, however, appeared to be more of a problem. These bearings, as shown in Figure 3, separate rotors A and B from each other and rotors C and D from each other. The rotors A through D are lettered from left to right in Figure 3. The two outside rotors, A and D, are fitted to the outer race of the bearings, while the two inside rotors, B and C, are fitted to the inner race of the bearings. This means that if the adjacent rotors are counterrotated, the relative speed of the large bearings would be the sum of the two rotor speeds. For these size and type bearings, and using grease as a lubricant, the bearing manufacturer recommended a maximum speed of 6300 rpm in order to obtain a relatively long bearing life.

The dimensions of the siren components contacting the bearings were considered to be quite critical. A highly accurate degree of machining was required during the actual construction of the siren. Special consideration was given to the depth and diameter of the bearing seats, and to the length of the spacers used between the inner races of opposite bearings. The length of the spacer between the inner races of the bearings was required to have the same dimension as that of each corresponding rotor which acts as a spacer between the two outer races. This perfect matching of dimensions was necessary in order to obtain the proper bearing preload.

Grease shields were attached to each rotor to cover the bearings. These shields were intended to prevent or at least reduce the loss of grease normally experienced from centrifugal force and air pressure on the bearings.

The siren shaft, also machined of Armco 17-4 PH stainless steel, was supported on both ends by cast aluminum supports. The total weight of the siren including the end supports was 53 pounds (24 kg).

SECTION III

HORN NETWORK

INTRODUCTION AND OBJECTIVES

A horn network having an acoustic capability that would match that of the siren was required to insure efficient transmission of acoustic power from the siren to the test area. The goals for the design of the horn network were: (1) a low cutoff frequency of approximately 115 cps; (2) a well damped structure; and (3) sufficient flexibility for spectrum shaping purposes. This cutoff frequency was chosen for several reasons. First, it was initially intended that this facility be used to test equipment having resonant frequencies above 115 cps. Also, the horn was to be designed to be compatible with an existing reverberation chamber. The chamber limited the size of the horn and thereby the cutoff frequency.

DESIGN APPROACH

A number of approaches were considered prior to the selection of the final design for the horn network. Two main approaches considered were: (1) a horn network with a throat large enough to encompass all four air passages; (2) one consisting of four separate horns matched to each air passage and hence to each noise source. The first of these approaches was discarded because of the impedance mismatch which would occur between the horn and the siren. Noise from the four separate noise sources would exit from the siren which has an area much smaller than the cross sectional area of the horn causing an impedance mismatch and a reduction in acoustic power transmitted to the test area.

The second approach was adopted but a number of items had to be investigated prior to proceeding with the final design. The items considered were: (1) four small horns with circular throats expanding conically or exponentially to a circular mouth to a point where the four horns would merge together; (2) four small horns also with circular throats expanding conically or exponentially to a square mouth at the merging point; (3) four small horns with square throats expanding pyramidally or exponentially to a square mouth. The first of these considerations was discarded because, from an air turbulence and impedance matching viewpoint, it would be advantageous to have as large a cross-sectional area as possible where the four horns merged together. The point of merger would be the same for a circular or square cross section, but the latter presented a larger cross-sectional area. The second of these considerations was rejected because of the problems involved in using the material selected to construct the horns since they would be required to change in cross section from circular to square. The horns that were designed are the result of further investigation of the third consideration which in reality was a compromise of the three approaches. The design was based upon both calculated and experimental data, with the main purpose of obtaining a usable, efficient, and versatile test tool. The siren and both horn sections are shown in Figure 8.

FIRST HORN SECTION

The first horn section was mounted on the same semiportable carriage as the siren. It consisted of an inner portion of four small horns and an outer shell, the space between being packed with very fine sand.

Weldable aluminum, 1/4 inch thick, was used to construct the four small horns. Two expanding channels were formed and then welded together along the full length of the horn as shown in Figure 9. The throats were approximately 1.5 inches by 1.5 inches square with a 0.5-inch radius on the four corners. The acoustic match is essentially the same as it would have been had the throats been circular, since a square of this size with half-inch radii in the corners is nearly circular in shape. The horns expand pyramidally over a distance of 30 inches to a horn mouth of approximately 6 inches by 6 inches. The horns were flared pyramidally and not exponentially in order to simplify construction, since the flare of one would not greatly differ from the flare of the other over this short distance and small cross section.

Each of these small horns was mounted on the same center line as the four inlet tubes and nozzles. The throat end of the small horns was slip fitted, via brass inserts, into the rotor case to reduce the air losses. The mouth ends of the small horns were merged together 30 inches downstream from the throats. The first horn section, mounted in front of the siren, is shown in Figure 10. It is mounted upon commercially available ball bushings by means of a ball bushing housing. (See Figure 11.) The ball bushings are mounted on the two shafts which, in turn, are mounted on the same semiportable carriage as the siren. This enables the first horn section, which has a total weight including the sand of about 200 pounds, to be pulled away from the siren with a horizontal force of about 5 pounds (Figure 12). This provides an easy access to the siren and insures that the four small horns will always be aligned with the openings in the siren housing.

SECOND HORN SECTION

The second horn section is also made up of a double wall construction and begins where the first horn section ends -- at the merger of four 6 inch by 6 inch mouth sections for a combined mouth dimension of approximately 12 inches by 12 inches. This, therefore, determines the throat size of the second horn section. The inner portion of the second horn section flares exponentially to a mouth with the approximate dimensions of 37 inches by 29 inches. The dimensions of the horn mouth were chosen so that the horn would be compatible with an existing reverberation chamber. The inner portions of both the first and second horn sections are shown in Figure 13. The inner walls of the second horn section were fabricated from 1/4 inch thick weldable aluminum, the four sides were cut from a sheet of aluminum bent to the proper exponential shape and welded along the four edges. The length of the second horn section was approximately 43 inches. The outside shells of both horn sections were constructed of 1/8 inch thick aluminum and attached to the inner portion via bolts and an aluminum channel. Taking into account the flare constants, the area of the mouth and the length of the horn, the cutoff frequency was calculated to be approximately 115 cps (References 9 and 10). The total weight of the second horn section, including the sand, was approximately 800 pounds. The second horn section is mounted on a three-wheeled carriage and can easily be positioned in front of, or removed from the first horn section.

The sand damping of these two horn sections has proved to be highly effective. The acoustic loss from the vibrating horn panels is negligible and sand leakage is nonexistent.

SECTION IV

FACILITY PERFORMANCE

INTRODUCTION

The performance of this facility has been evaluated in detail and a large amount of data collected and analyzed. This report presents only a portion of the total collected data. It includes performance data on the original configuration of the facility, and on modified configurations at various stages of development. Figure 14 summarizes some of the more pertinent operating characteristics of the facility.

OVERALL SOUND PRESSURE LEVEL

The maximum overall rms sound pressure level measured across the 1 x 1 foot cross section of the small horn was 172 db (re: 0.0002 dynes/cm^2). The maximum level across the large horn mouth was 165 db for a reverberant room and 163 db for a semianechoic room. The SPL profile for the semianechoic configuration is shown in Figure 15.

The lobes between 20 degrees and 90 degrees on both sides of the room represent a constant overall sound pressure level and a nearly identical spectrum. The drop-off in sound pressure level with distance as shown in Figure 15 is the same regardless of the power setting of the siren.

SPECTRUM

The spectrum of the noise output of the siren was evaluated by performing octave band analyses, one-third octave band analyses, and constant bandwidth narrow (3.5 cps at the half-power point) band analyses. The investigation included analyses of the noise output of each rotor operated separately and in combinations of two, three, and four. A great number of speed combinations were investigated, pressure and air mass flows were varied, the effect of rotating all four rotors in the same direction versus counterrotation was examined as well as the effects of modulating the rotor speeds. In addition various physical configurations of the original siren setup were altered and investigated until a spectral output of the siren was obtained that met the requirements of a good test spectrum, namely, it was continuous and contained random characteristics.

The best spectral output obtained from the siren is shown in Figure 16. This represents a 3.5 cps bandwidth analyses and shows a continuous spectrum with a minimum of discreteness. Figure 17 is a one-third octave band analysis of the same siren output. The spectral output of the original siren configuration, though, differed greatly from that shown in Figure 16. The original spectrum did not have the continuous, relatively equal spread of energy as shown in Figure 16, but rather approached a line spectrum and showed large dropoffs from one frequency to the next. Figure 18 is a typical representation of these original spectra since the same discontinuity existed regardless of the rotor speeds. The frequency of the peaks, however, did vary with a variation in rotor speeds. Some of the rms peaks for different rotor speed combinations reached as high as 25 db above the surrounding valleys as shown in Figure 18.

The spectrum consists of the harmonic series of each rotor plus the sum, difference, and multiplication of the four harmonic series. Eight or more of the higher pressure components are easily traceable to the rotors that caused them. The main components shown in Figure 18 are 4 and 8 times the fundamental frequencies, the four fundamental frequencies being equal to the cps of each rotor.

Two problems were realized as a result of looking at the above described analysis. First the rms amplitude of some of the pressure components was far above the neighboring peaks. Second, the distances between some of these peaks, in cps, were far too large for the siren to be an effective test tool. The spectrum shown in Figure 18 was considered unsatisfactory, especially in the event resonant frequencies of a test item were unknown and could possibly be located in some of the deep valleys of the spectrum.

Air Inlets

The first of these two problems was partially solved by making some changes in the original siren configuration. The first change was to reduce the number of air inlets from four to three. It was discovered, by means of narrow band analysis of single rotor spectra, that there was considerable cancellation of harmonic components due to the symmetry of the four air inlets. Figure 19 shows single rotor spectra with four and three air inlets. The acoustic energy, when using four air inlets, was redistributed from a large number of components to only a few. A similar effect was observed when two air inlets were used 180 degrees apart. Air supplied by one or two air inlets, located 90 degrees apart, did not result in cancellation as shown in Figure 19 for the four-inlet configuration, but rather resembled the three-inlet configuration.

It was also observed that for a given air mass flow and pressure the overall sound pressure level was 2 to 4 db lower when the two inlets were located 180 degrees apart as compared to the two inlets located 90 degrees apart. The three-air inlet configuration was considered most desirable because a higher mass flow at a lower pressure can be passed to the siren than when using one or two inlets. Air inlets located in an unsymmetrical manner should be even more desirable for this particular siren since using three inlets in the present configuration still results in two inlets being 180 degrees apart. The effect on the four-rotor spectrum of reducing the number of air inlets from four to three can be seen by comparing the top curve of Figure 20 with Figure 18. For a constant overall sound pressure level, the peak-to-valley distance has been reduced.

Rotor Housing

In addition to the symmetry of the air inlets it was discovered that the rotor housing was also contributing to the large differences between some peaks and valleys. Figure 20 clearly shows the effect that the rotor housing has on the spectrum. The rotor housing, as discussed earlier, was designed specifically to increase the efficiency of the siren by eliminating the air losses throughout the siren as much as possible. It has been theorized that this design aspect along with the large open areas of the modulating portion of the rotors was causing the effect shown in Figure 20. The air from any one inlet, as it was blocked by a rotor blade, would be able to circulate throughout the siren because of the large open areas of the rotors. The rotor housing would prevent this air from escaping into the surrounding room and the air would be forced to exit through all four horns. This results in the cross-modulation effect being by-passed and a greater concentration of energy in the main harmonic components. These main harmonic components are the 4th, 8th, and 16th of the harmonic series of each rotor. The influence of the four small horns is clearly shown with the main components being multiples of four.

Attempts were made to resolve this problem without removing the rotor housing. The housing was depressurized by various means, but this did not eliminate the effect on the spectrum contributed by the rotor housing. The air was still channeled by the housing into the four horns. Removing half of the rotor housing reduced the effect, but the spectrum still was not as good as it was with the entire housing removed. An octave band comparison of the siren with and without the rotor housing shows approximately a 5-db increase in sound pressure level in the first two octave bands, 37.5 to 75 and 75 to 150 cps with the housing removed, and a 2- or 3-db reduction in the octave bands above 500 cps with the housing removed. Pressure, mass flow and velocity of the air flow has little or no effect on the relative comparison of spectra with and without a rotor housing for this particular siren. Most likely the rotor housing effect would be eliminated without removing the housing if stators could be added between the rotors. The air flow would then be restricted to a passage straight through the siren from the inlet to the opposite horn and thereby enhance the cross-modulation effect.

As a result of the effect described above, operation of the siren without the rotor housing was adopted as an operating parameter. The maximum efficiency of this system with the housing was approximately 10 percent; this efficiency was reduced to 8 percent with the removal of the housing.

Rotor Speed Ratios

A solution to the second problem of large gaps between peaks was sought by first trying to find a four-rotor speed combination which resulted in the largest number of discrete peaks. Rotor speed ratios based on the 4th root of various numbers were investigated. The 4th root ratios were used since they are irrational and the resulting harmonic series from each rotor contained discrete peaks which did not exactly coincide with the peaks of the harmonic series of the other rotors. Figure 21 shows the best spectrum that was obtained by this method. The speed ratios in this case from the downstream rotor were $(2.0)^{1/4}$, $(2.0)^{1/2}$, $(2.0)^{3/4}$. The spectrum shown in Figure 21 is relatively good in comparison to the original spectra. This spectrum represents the combined development efforts of reducing the number of air inlets, removing the rotor housing, and obtaining speed ratios that resulted in the largest number of discrete peaks. The effect of the rotor housing and the four air inlets on the spectrum created by these rotor speed ratios is the same as that shown previously for the other rotor speed ratios. The spectrum shown in Figure 21 is repeatable, from a frequency standpoint, with time; only the amplitude changes with time. However, a degree of noncontinuity and discreteness still existed.

Rotor Rotation

The direction of the rotation of each rotor relative to the adjacent rotor was investigated for its effect on the spectrum. By means of a narrow band analysis it was found that there is no significant effect on the spectrum when the rotors are rotated in the same direction as compared to counterrotation. The same discrete peaks exist at approximately the same rms amplitude regardless of whether the rotors are all rotated in the same direction, whether the first two are rotated in one direction and the last two in the opposite direction, or whether all four rotors are counterrotated. Since counterrotation of the rotors results in the speed of the large bearings being equal to the sum of the two rotor speeds, rotation of the rotors in the same direction would result in a lower bearing speed and therefore longer bearing life. (See Figure 3.) However, when the adjacent rotors are rotated in the same direction there is a coupling effect between the rotors which is significant when air pressure in excess of 5 psig is applied to the siren. The rotor operating at the higher speed causes an increase in the speed of the lower speed rotor. The magnitude of this coupling depends on the air pressure and mass flow. Individual rotor speed control is virtually impossible at high pressures when the rotors are rotated in the same direction. For this reason and since the direction of rotation has no apparent effect on the spectrum of this siren, counter-rotation was adopted as an operating parameter.

Rotor Speed Modulation

The frequency modulation of the rotor speeds was considered next to further improve the spectrum. This investigation started with the spectrum shown in Figure 21. It was reasoned that, if the energy represented by the discrete peaks shown in Figure 21 could be shifted to some frequency where it was relatively low and then shifted back to its original position, after a certain length of time the spectrum would represent an averaged rms spectrum. It would be average because the rms level would change with time and with the sweep of the rotors. If this time value were kept short enough, then for all practical purposes, the spectrum would be continuous and nondiscrete. The investigation for this spectrum became rather lengthy and for this reason only the results are presented.

The spectrum that was adopted for general use is shown in Figure 16. Notice that the analyzer frequency sweep rate, the recorder writing speed, and the recorder paper speed are the same for all the narrow band spectra shown in this report. This was done in order to make a direct comparison possible between the spectra of Figure 16 and all other spectra in this report.

The spectrum shown in Figure 16 is conspicuous by the absence of the high pressure components and the deep valleys; it is continuous and relatively smooth. To obtain this spectrum each rotor was swept over a different rpm range thereby distributing the power more evenly over the frequency range. The rpms and ranges used to obtain this spectrum are not consistent with the starting point of the investigation, but do represent optimum operating conditions discovered.

A number of parameters had to be considered prior to the development of a suitable technique for sweeping the speeds of the rotors. Some of the different items are: (1) the sweep rate of each rotor; (2) the sweep range of each rotor; and (3) the starting rpm for the sweep of each rotor. The choices of the sweep rate and sweep ranges for each rotor are the result of a compromise since both were dependent upon the same limiting factor, that being the surge in current which accompanied each motor as it swept to a higher rpm. The rate and range of sweep affected the current as did the air load on each rotor.

Operating the siren under maximum load conditions, the rate and ranges were chosen so that the current did not surge past the allowable limit. The starting point for the sweep of each rotor was chosen as a result of a large number of experimental investigations which were based on the parameters described above.

A schematic for the siren sweep control circuit is shown in Figure 22. This particular sweep configuration operates from a common 110 V AC electrical source. The sweep of each rotor is individually controlled and arranged so that none of the sweeps is in phase. The acceleration and the sweep distance are different in each case. These precautions were taken in order to keep the noise output as random as possible. The period of each sweep cycle can be varied anywhere from 1.5 seconds to 6 seconds, while the sweep range can be varied from 50 to 1000 cps.

The sweeping serves two main purposes. It is an added means of modulating the air streams and therefore enhances the possibility of random amplitude distribution. The sweeping rotors also result in a constantly changing harmonic series for each rotor. This, in turn, adds to the cross modulation of the harmonic components and to the spreading of these components over a wider frequency range. Therefore, after a short period of time, practically all frequencies over the band of 40 to 16,000 cps show sufficient energy for the spectrum to be considered continuous.

In analyzing the noise output of this siren, the data shown in Figure 16 was recorded on a full reel of tape and played back through the narrow band analyzer. The analyzer frequency was swept at a rate of 0.5 cps. With each rotor sweeping cycle equal to 3.5 seconds, or less, and each bandwidth equal to 3.5 cycles, the analyzer was swept slow enough for each 3.5 cycle band to "see" at least two complete rotor sweeps. The data in Figure 16 therefore, represents an rms averaged level for each narrow band of noise.

The spectrum obtained by the sweeping rotors is a great improvement over the original spectra of this siren. The sweeping spectrum is relatively smooth, continuous, and has random characteristics.

Amplitude Distribution

The amplitude distribution characteristics of the siren while operating with constant and sweeping rotor speeds closely follow the Gaussian distribution. Figure 23 shows a comparison of certain frequency bands for both nonsweeping and sweeping rotors with a Gaussian distribution curve. Notice the flat portion of the curve representing the 40 to 125 cps band for constant rotor speeds. This curve shows sinusoidal characteristics due to the large peaks that appeared previously within this band. The low frequency bands for sweeping rotor speeds follow the Gaussian distribution closely while the high frequency bands for both nonsweeping and sweeping rotor speeds have a greater density about the mean value. The sweeping, however, does result in an improvement in all bands over the nonsweeping rotor speeds.

Multirotor Comparison

Figure 24 compares 1-rotor, 2-rotor, 3-rotor, and 4-rotor spectra. The comparison shows how the spectrum becomes more continuous with the addition of each rotor. The question arises as to whether four rotors are the optimum number or whether a fifth or sixth rotor could be used to obtain a more continuous spectrum. It becomes largely a question of efficiency. If too many additional rotors were added downstream, the upstream rotor would become less useful. The optimum number of rotors would be determined by the point at which the best spectrum would be obtained with no loss of acoustic power.

Spectrum Shaping

The spectrum shaping capability of the siren is limited to either changing the rotor speeds or changing the shape of the horn network. Spectrum shaping by changing the rotor speeds is in itself quite limited and is not sufficient to meet the needs. Since the rotors of the siren are frequency modulated up to 1000 rpm, the fundamental frequency is shifted up to 17 cps. The change in the spectrum caused by the sweeping rotors is insignificant when observed on a one-third or octave basis. Figure 25 shows the extent of the spectrum shaping that can be accomplished by operating the siren at extremely high and low speeds. A general shaping can be attained but the level in any one-third octave band is not adjustable with respect to another band and therefore a fine shaping capability is not available through changing the rotor speeds.

Additional shaping can be attained by changing the shape of the horn network. In this case it consists of the removal of the large horn section resulting in an increase in the cutoff frequency of the horn network. The effect on the spectrum of removing the large horn section is shown in Figure 26. This figure also shows the effects of low rotor speeds with the large horn, and high rotor speeds without the large horn.

Further spectrum shaping can also be accomplished by placing panels and curtains between the siren system and the test area. This method of spectrum shaping (Figure 27), however, is less desirable since it is accomplished only with a loss of the acoustic power transmitted to the testing area.

Other spectrum shaping devices which are currently under development and look very promising are an expansion chamber, a lined horn and a perforated panel before a rigid wall. A subsequent report will discuss the findings of this investigation.

Rms Versus Peak Sound Pressure Levels

Both rms and peak measurements were recorded. The one-third octave band spectra for rms and for peak values are shown in Figure 28. In this case the recordings were made while the siren was operating and represent the difference between rms and peak values for this type noise source. The difference in the overall sound pressure levels was approximately 7 db. The difference in the spectrum varies with the frequency band, being negligible in the low frequency bands and ranging from a difference of 2 db in the midrange to 7 db in the higher frequency bands.

Pressure and Air Flow

The effects of pressure and air mass flow on the overall sound pressure level measured in the small horn mouth and the large horn mouth are shown in Figures 29 and 30. The maximum overall sound pressure levels measured are 172 db rms and 165 db rms, respectively. The generation of acoustic power becomes inefficient at pressures over 20 psig and air mass flow over 2.0 lb/sec. The pressure was measured by way of a pitot tube 12 inches upstream from the nozzles in the 2-inch diameter air inlet line (See Figure 31.)

The effect on the spectrum of increasing the air mass flow and pressure is minor aside from raising the level of the entire spectrum. At extremely low mass flow and pressure, the spectra varies from those measured at higher flow and pressure because the aerodynamic input is still an insignificant factor. Figure 32 shows the effect of air mass flow and pressure on the spectrum. A narrow-band analysis at different pressures shows no other significant change in the spectrum due to air mass flow and pressure.

SECTION V

CONCLUSIONS

After studying the total collected data it becomes apparent that the construction of a siren of this type is not simple and straightforward. This siren with sweeping rotors meets the requirements for a useful test tool. It has a near Gaussian amplitude distribution and a continuous spectrum. The operation of a siren of this type under the conditions of constant rotor speed and without sweeping the rotors over a certain range, could result in a spectrum with a high degree of discreteness. The spectra of some sirens, though, would not necessarily appear as objectionable as others. The degree of noncontinuity for a siren could be reduced, but probably not eliminated entirely, by (1) finding an optimum design for rotor shapes, rotor size, and rotor speeds, (2) adding stators between the rotors, (3) finding the optimum number of rotors, and (4) carefully considering all other parameters such as horns, nozzles, air pressure, mass flow, etc.

Some sirens which have been tested in the past have spectra considerably less discrete and more continuous than the spectra of this siren when operated under constant rotor speed conditions (References 3 and 4). It was originally felt that the multiple air inlets were responsible for the discreteness of the spectrum. While this was true to a certain degree it was proven that there was no great difference in the spectra when using one or three air inlets. It is now felt that the problem lies not with the multiple air inlets, but with the design of the rotors. The modulating portion of the rotors of this siren were all 80 to 85 percent open, while some of the rotors tested in the past had open areas ranging from 42 to 85 percent. At the time this siren was designed, previous test data indicated that individual rotor open areas of 80 to 85 percent would result in the best siren output and in an effective open area, looking through all four rotors, of 45 to 50 percent. If by siren output, it is meant acoustic power output, this may be the case. The large rotor open areas should result in the greatest acoustic power output. However, if one considers the siren output in terms of spectrum continuity and randomness, large rotor open areas may not produce the best siren output since they create a noncontinuous spectrum. Using the data gathered on these tests and taking into account the recommendations resulting from previous tests, it can only be said that the optimum rotor openings lie between the large openings of this siren and the smaller openings of previously tested sirens.

Future plans call for an investigation to determine more accurately the effect of rotors having smaller openings.

SECTION VI

SUMMARY

One of the main objectives in preparing this report was to assist in the future development of this type siren. For this reason the shortcomings and the problems rather than the advantages of this type siren have been stressed.

It is felt that this siren and facility have successfully met the design goals which had been established for them. These goals, however, were met only through a development study and as a result of certain modifications to the original design. Figures 16 and 23 demonstrate that a wide band, random continuous spectrum can be attained. The maximum power level of this siren is greater than the design goal and certain spectrum shaping capabilities, while not too extensive, do exist.

This type siren has great possibilities which can be brought out only by further development programs. Some are now in progress in both the Air Force and industry.

APPENDIX

FACILITY DESCRIPTION

INTRODUCTION

The original facility configuration is described herein and in some detail since the siren was designed around an existing air supply, and all the measurements used for the analysis of the siren were taken in this facility. At the time this report was being prepared, the facility was undergoing considerable change and modification to eventually become a one-quarter scale model of the large sonic fatigue facility located at Wright-Patterson Air Force Base (References 8 and 11).

ACOUSTIC CHAMBER

The original enclosure was a room 19 feet long, 10 feet wide, and 8 feet high with the walls and ceiling constructed of commercially available acoustic panels. These panels consist of an outer surface of solid sheet metal, an inner surface of perforated sheet metal, and four inches of fiber glass sandwiched in between the two surfaces. The inside walls and ceiling of the enclosure were covered with 5/8-inch thick plasterboard to obtain a reverberant field within the test area. Progressive wave transmission was obtained by covering the inside walls with polyurethane curtains. The room contained the siren, two horn sections, an 11 x 11-inch cross-sectional test section for testing small items, and a 10 x 10-foot square test area for large items. Entrance to the room was gained through a double door which had an opening 5 feet wide and 6 feet, 10 inches high. Above the room was an air exhaust muffler capable of exhausting air at the rate of 20 pounds per second. Figure 1 shows a view of this room.

AIR SUPPLY

According to the original design, air was to be delivered to the siren through four standard fire hoses which passed through the rear wall of the acoustic chamber from a 12-inch diameter, 4-foot long plenum. Preceding the plenum was a 90-degree on-and-off air valve which was connected into the air supply system via reducers between the plenum and a 4-inch air line. An orifice plate was located in the 4-inch air line so that an accurate monitoring of the air flow to the siren was possible. Air to the 4-inch air line came from a 24-inch line via a 12-inch and a 6-inch line.

The compressed air supplied to the siren originated from two De Lavel compressors, one with a rated output of 7800 cubic feet per minute, and the other 16,800 cubic feet per minute. Either one of the compressors or a combination of the two, in series or parallel, could be used to supply compressed air to the siren. When operated separately, each had a discharge pressure of 28 psig. When the two compressors were operated in series, a high mass flow at a higher pressure was attained. The maximum amount of air supplied to the siren to obtain the maximum sound pressure level was 10,000 cfm at 50 psig. Figure 31 is a schematic of the air supply system.

INSTRUMENTATION AND CONTROLS

An instrumentation and operating booth (Figure 33), located outside the acoustic chamber, contained the following controls and instrumentation.

1. Speed indicating meters and controls for controlling the speeds of the four siren rotors.

2. Pressure gauges which indicate the pressure on both sides of the orifice plate and which indicate the static and total pressure via a pitot tube in the air line 12 inches upstream from the siren.

3. Power supplies for the Altec cathode followers and condenser microphones located near or on the test specimens.

4. Bruel and Kjaer one-third octave band analyzers, model numbers 2107 and 2111, and recorders, model numbers 2304 and 2305.

5. An Ampex 300 tape recorder.

6. Oscilloscope, voltmeter, ammeters, amplifiers, and other associated equipment.

Figure 34 is a schematic of the instrumentation and controls.

The following additional instrumentation is also available:

1. Hewlett Packard Wave Analyzer - Model 302A.

2. Gulton Amplitude Density Analyzer System, developed specifically for the RTD Sonic Fatigue Facility*.

3. Sigmatron Random Signal Generator Model GA 1000.

Figure 35 shows a typical free field calibration curve for parallel incidence for the condenser microphones used in this facility. The one-third octave band spectra shown in Figures 17 through 21, 24 through 28, and 32 were not corrected for the deviation between 5000 cps and 20,000 cps from the flat portion of the response curve shown in Figure 35. This deviation should be taken into account when studying these one-third octave band plots.

NEW FACILITY DEVELOPMENT

The facility currently being developed to contain the wide band siren is a one-quarter scale model of the large sonic fatigue facility at Wright-Patterson Air Force Base, Ohio. Upon completion, the necessary power supplies will be available so that not only the wide band siren can be utilized in the facility, but also the high and low frequency pure tone sirens. An air modulator or bank of speakers will be used to generate acoustic energy. Other changes include an additional horn section to lower the cutoff frequency to 50 cps, an enlarged reverberation room (from 1570 ft^3 to 2400 ft^3), and devices to facilitate spectrum shaping.

The facility will utilize the instrumentation complex of the large sonic fatigue facility for data measurement, reduction and analysis (Reference 8).

---

*This facility is referred to in the literature as the "ASD Sonic Fatigue Facility." At the time of the AFSC reorganization it was transferred to the then newly created Research and Technology Division (RTD).

REFERENCES

1. D. M. Forney, "Experimental Techniques and Equipment for Acoustical Fatigue Research and Development," Symposium on Acoustical Fatigue, ASTM STP No. 284, March 1961, pp. 54-65.

2. R. A. Bianchi, R. T. Bradshaw, J. H. Farrell, and F. E. Reed, Survey and Evaluation of Sonic Fatigue Testing Facilities, ASD-TR-61-185, Aeronautical Systems Division, Wright-Patterson Air Force Base, Ohio, March 1962. Contract No. AF 33(616)-7003, CONESCO, Arlington, Mass.

3. H. E. von Gierke and J. N. Cole, "Acoustic Siren for Generating Wide Band Noise," U.S. Patent No. 2.912.958, 17 November 1959.

4. J. N. Cole, H. E. von Gierke, H. L. Oestreicher, and R. G. Powell, "Simulation of Random Acoustic Environments by a Wide Band Noise Siren," Bulletin No. 27, Part II, Shock, Vibration, and Associated Environments, Office of Secretary of Defense, 1959.

5. J. N. Cole, R. G. Powell, H. L. Oestreicher, and H. E. von Gierke, "Rocket and Jet Noise Simulation by the New Wide Band Noise Siren," Compendium of Symposium Papers, ASD-TR-61-394, Vol 1, Aeronautical Systems Division, Wright-Patterson Air Force Base, Ohio, September 1961.

6. J. N. Cole, R. G. Powell, H. L. Oestreicher, and H. E. von Gierke, "Acoustic Siren for Generating Wide Band Noise," Journal of Acoustical Society of America, Vol 35, No. 2, February 1963.

7. J. P. Henderson and K. M. Hankel, "Design and Performance Data of a Unique Broad Band Acoustic Test Facility," Bulletin No. 30, Part V, Shock, Vibration, and Associated Environments, Office of Secretary of Defense, May 1962.

8. A. W. Kolb and O. R. Rogers, "The ASD Sonic Fatigue Facility," Ibid.

9. American Standards Association, American Standard Acoustical Terminology, 25 May 1960.

10. L. L. Beranek, Acoustics, The McGraw-Hill Book Co., New York, 1954.

11. C. M. Harris, Handbook of Noise Control, The McGraw-Hill Book Co., New York, 1957.

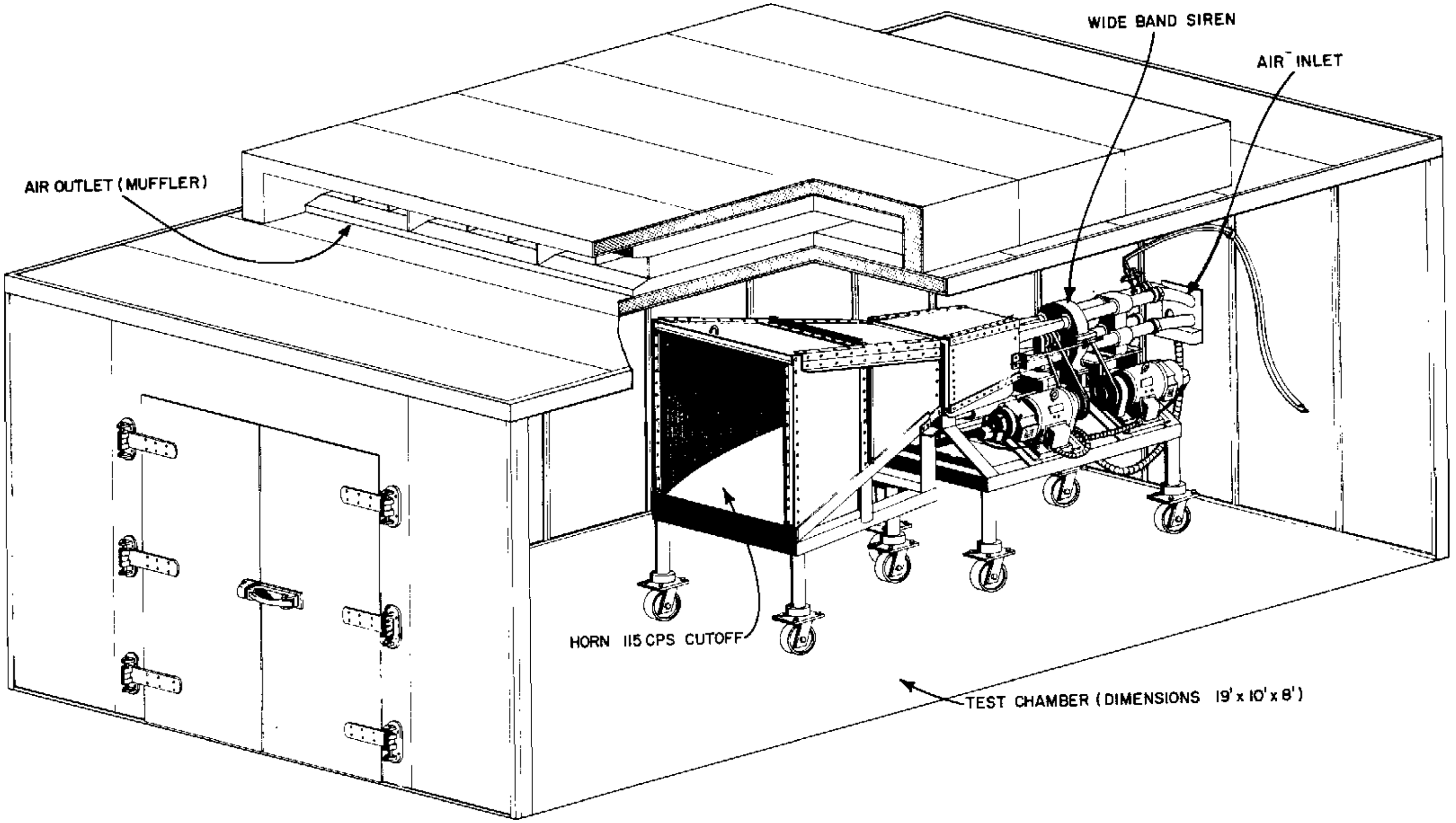


Figure 1. Wide-Band Noise Facility

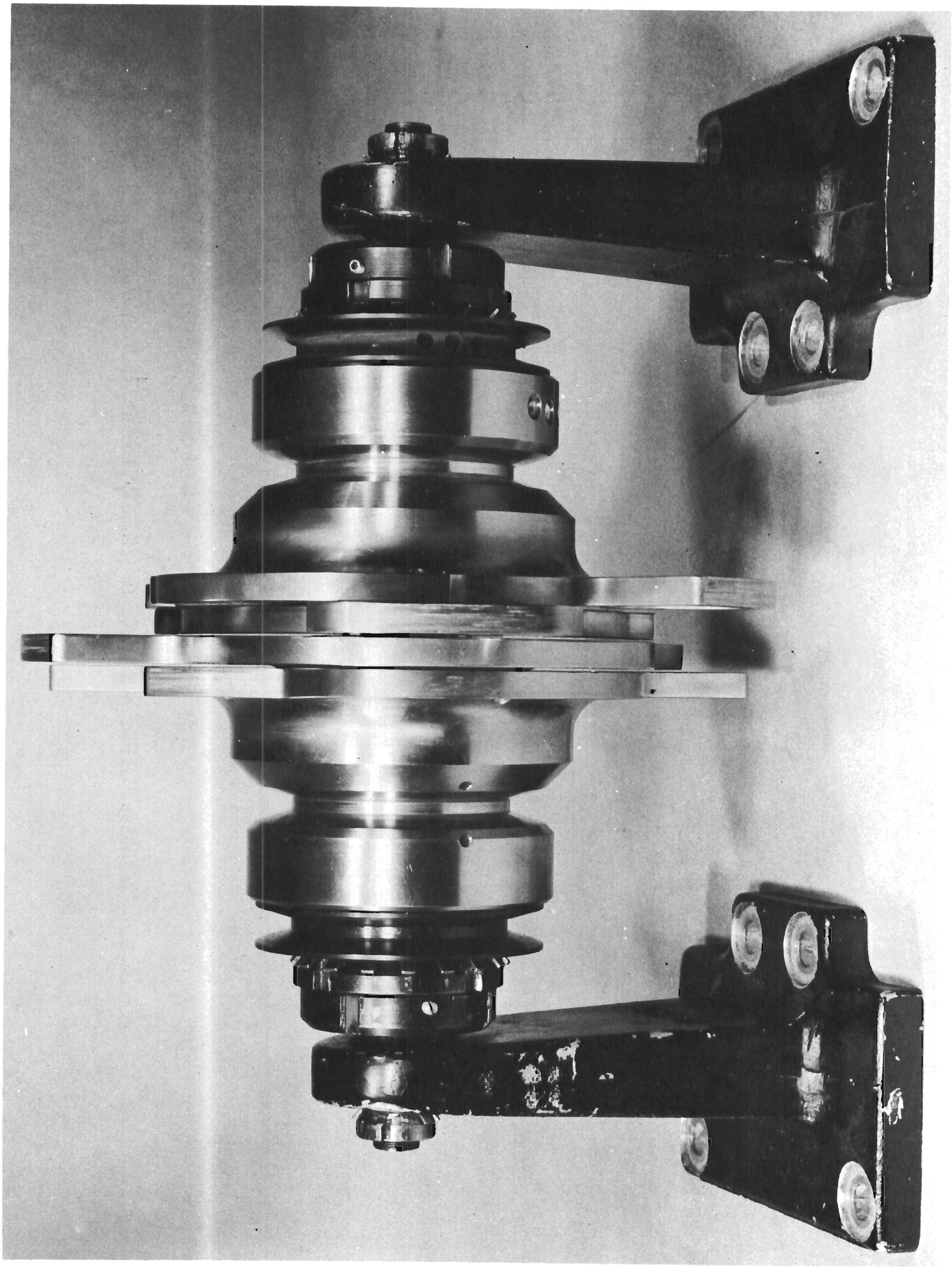


Figure 2. Wide-Band Siren - Side View

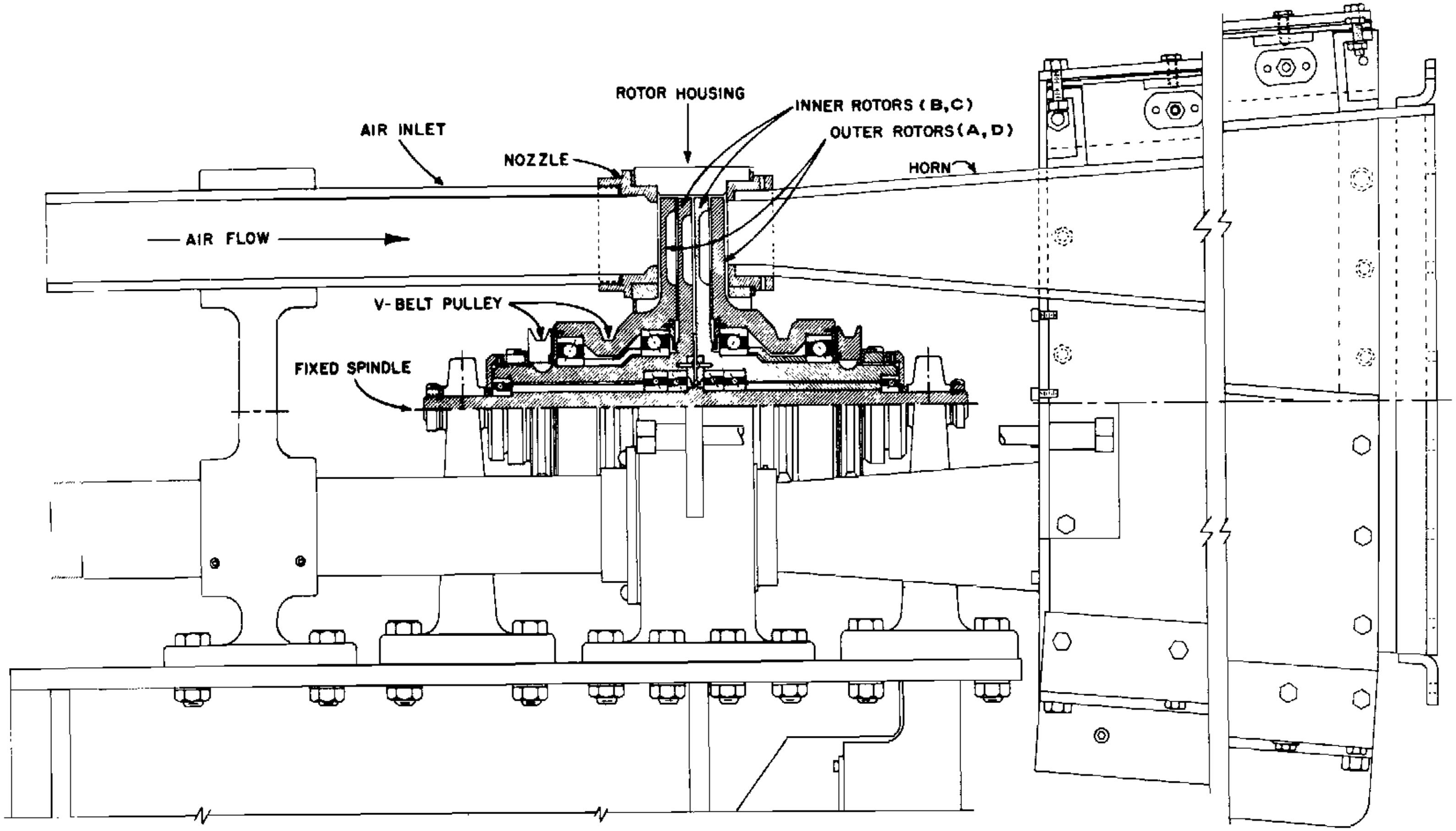


Figure 3. Wide-Band Siren - Cross-Sectional View at 45 Degrees

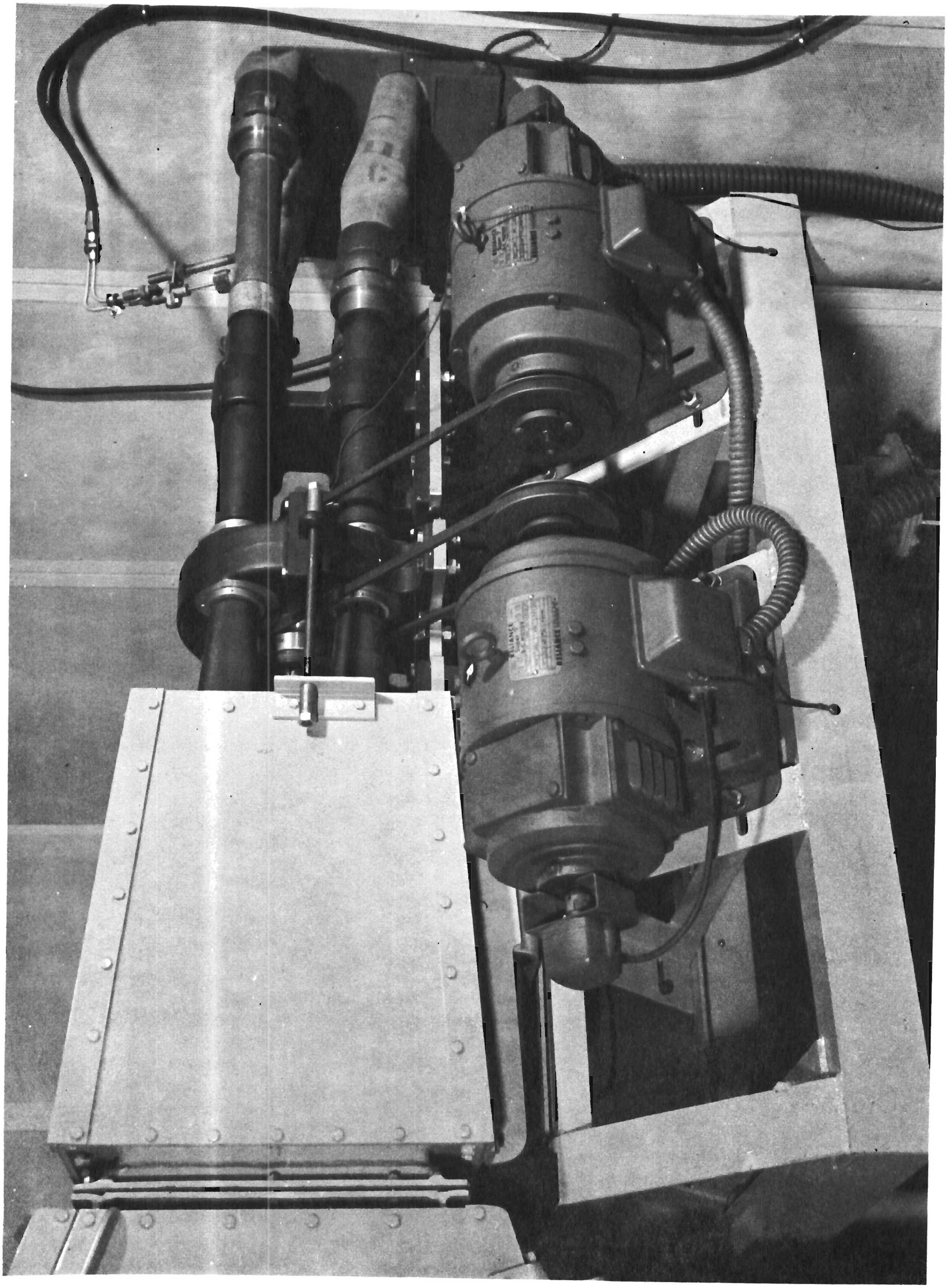


Figure 4. Wide-Band Siren System - Side View

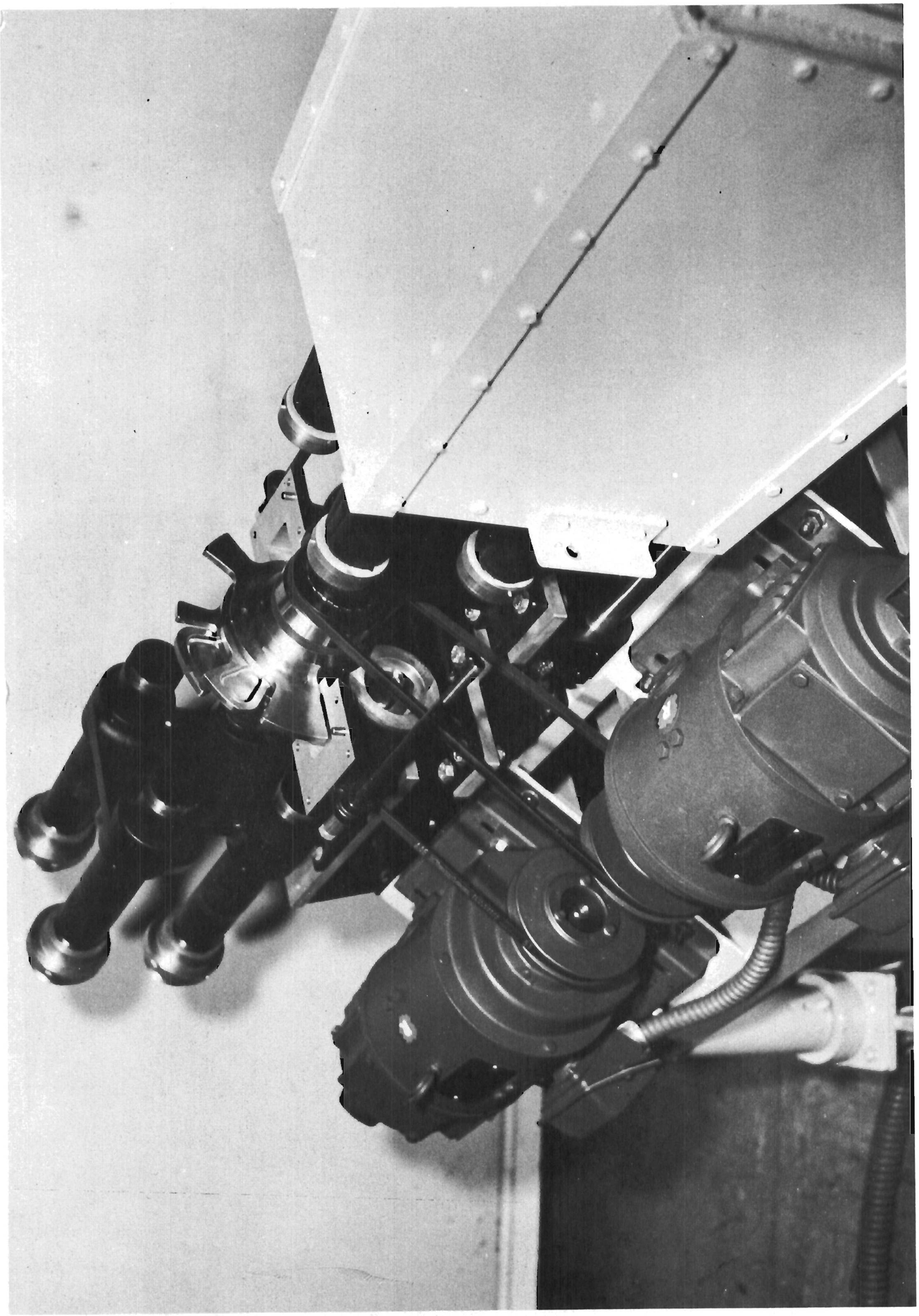


Figure 5. Wide-Band Siren with Top Half of Rotor Housing Removed

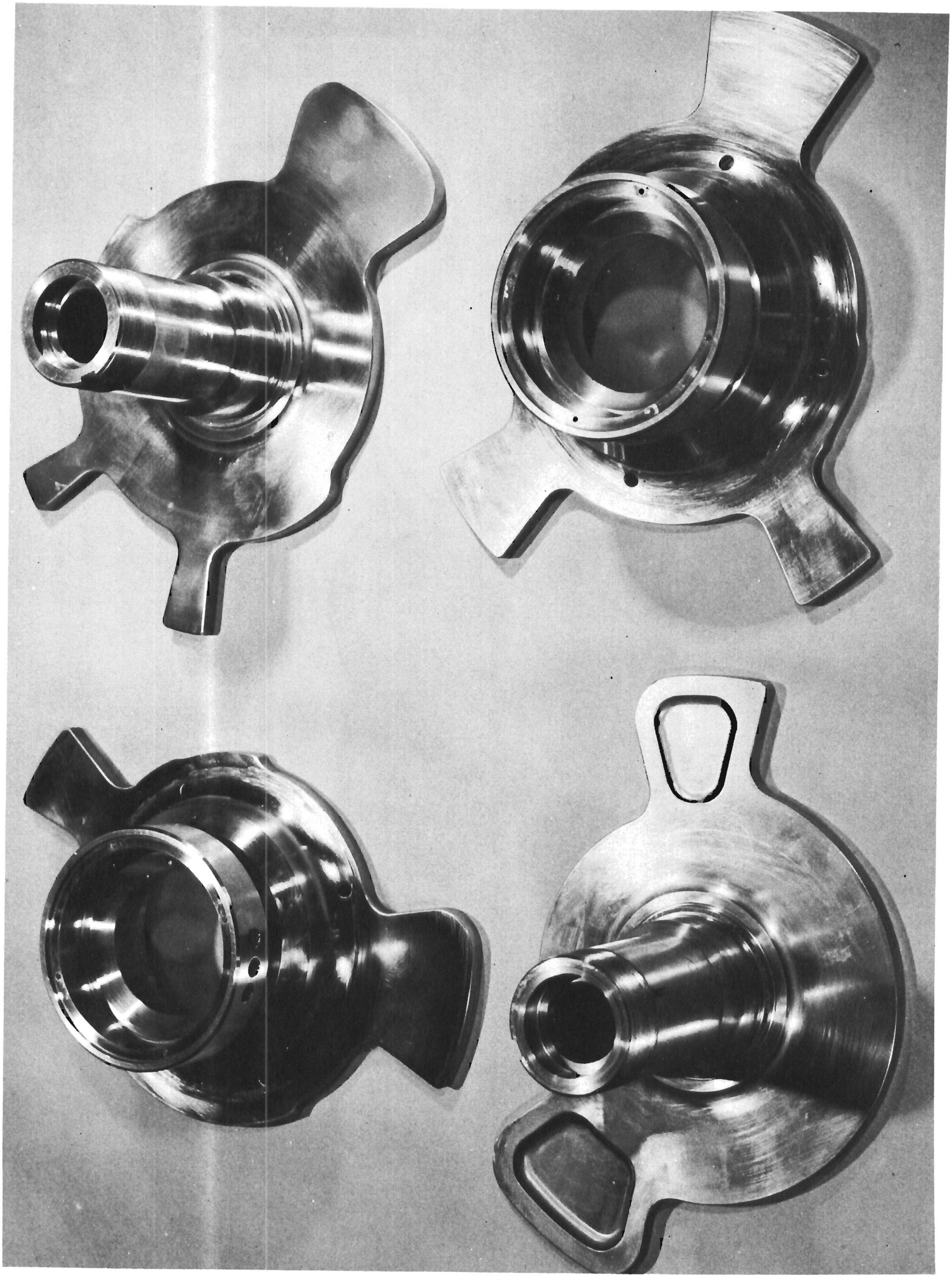


Figure 6. Siren Rotor Blades

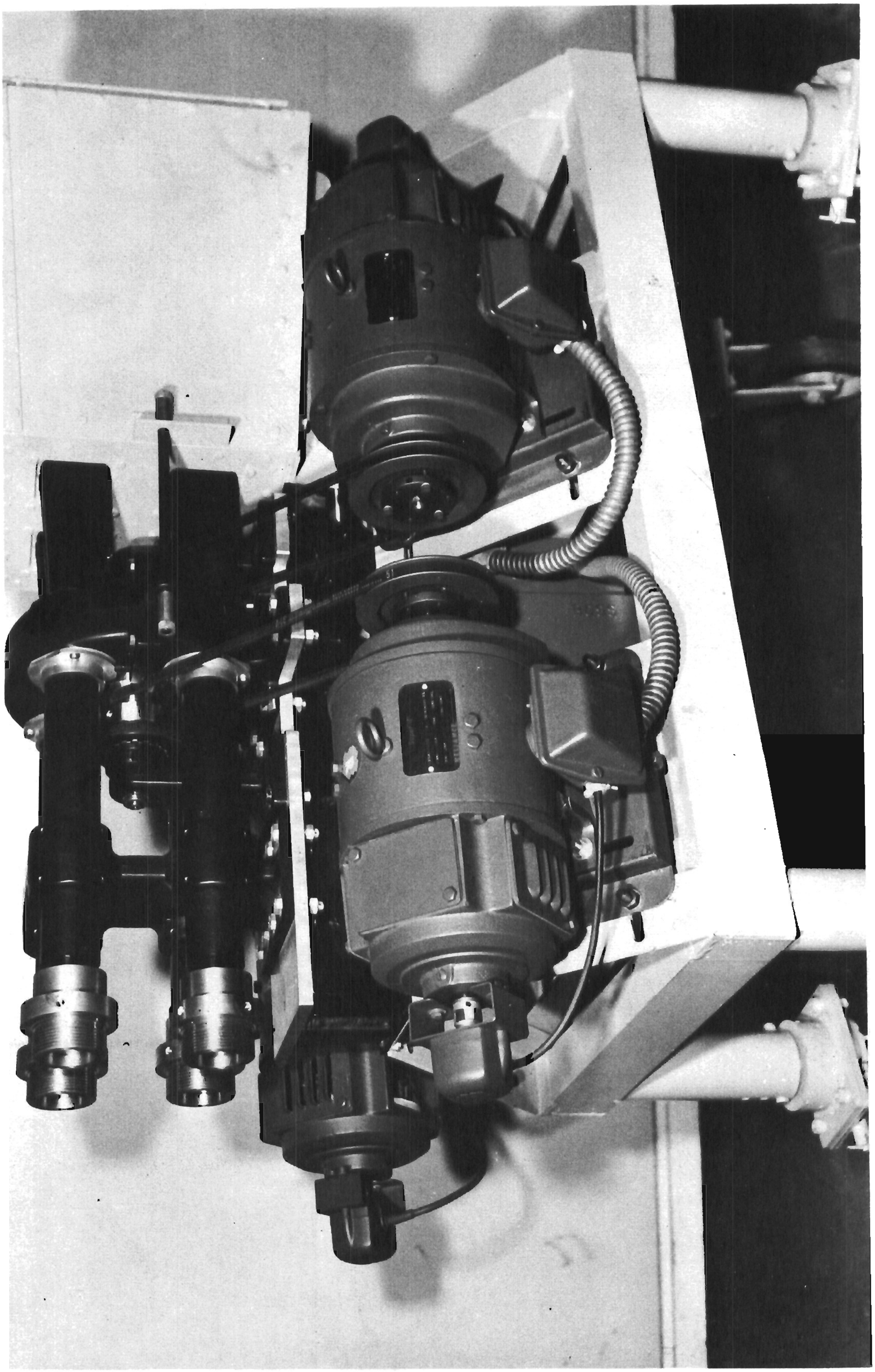


Figure 7. Wide-Band Siren Motors and First Horn Section

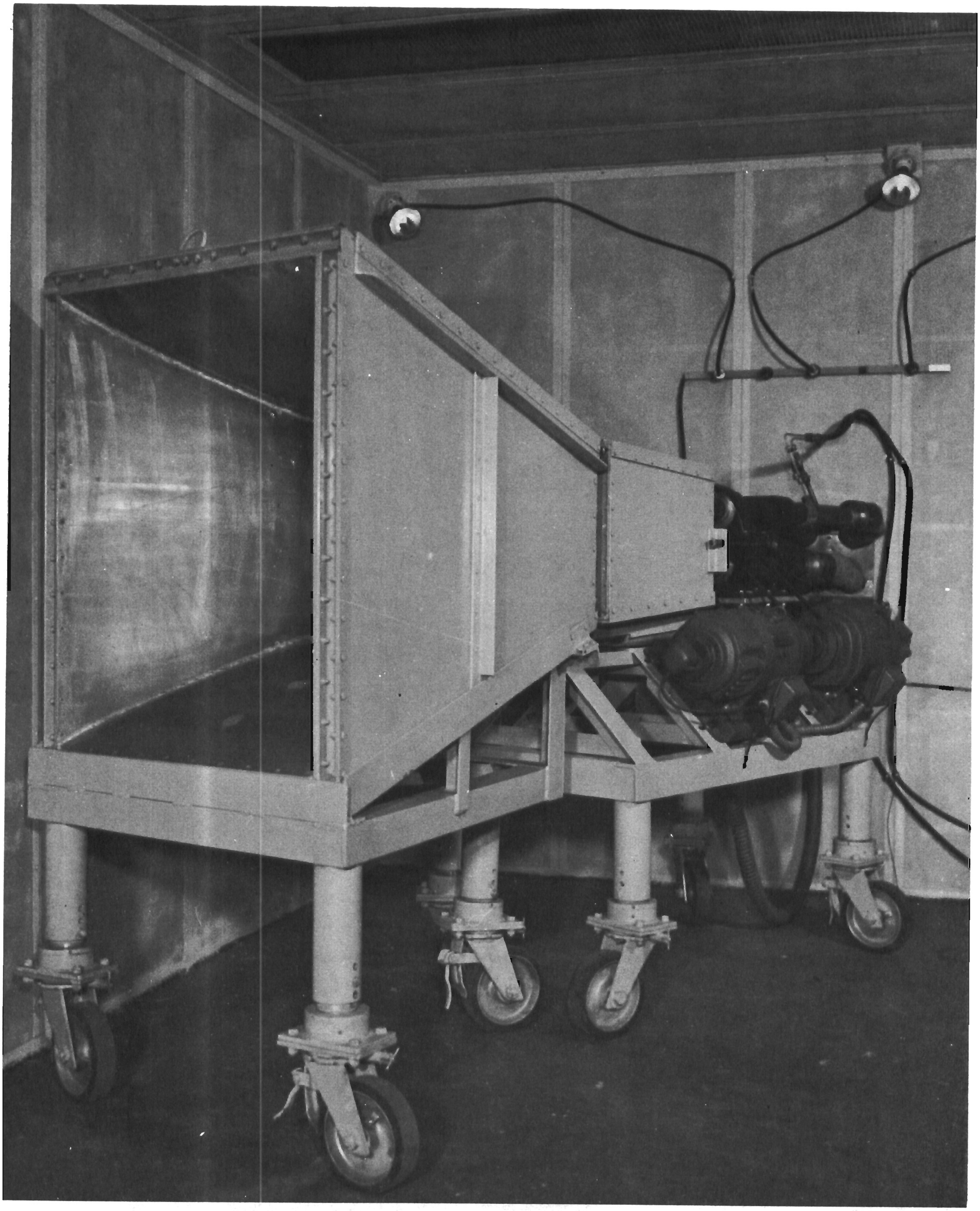


Figure 8. Horn Network and Siren

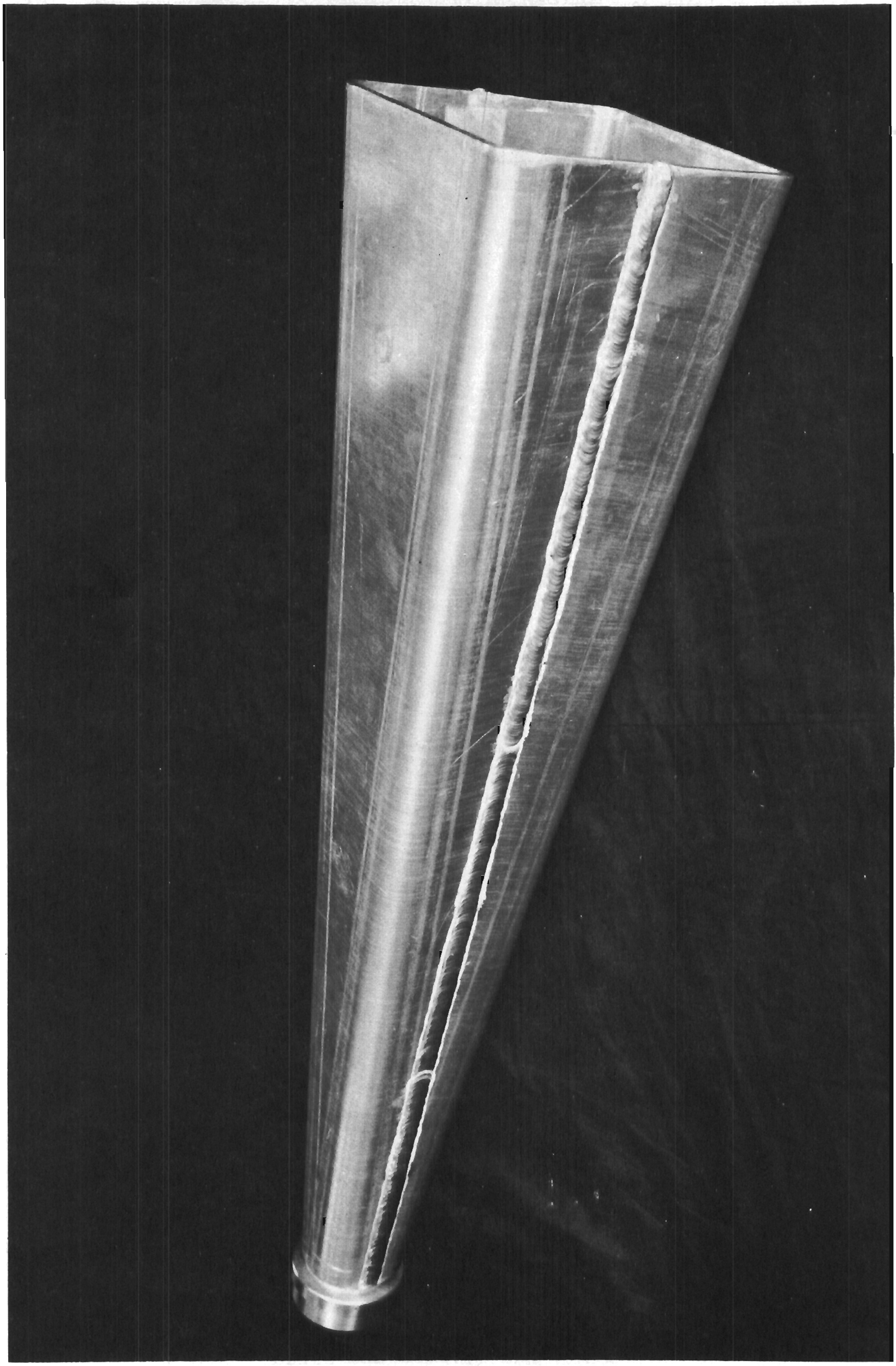


Figure 9. Typical Construction of Small Horn Section

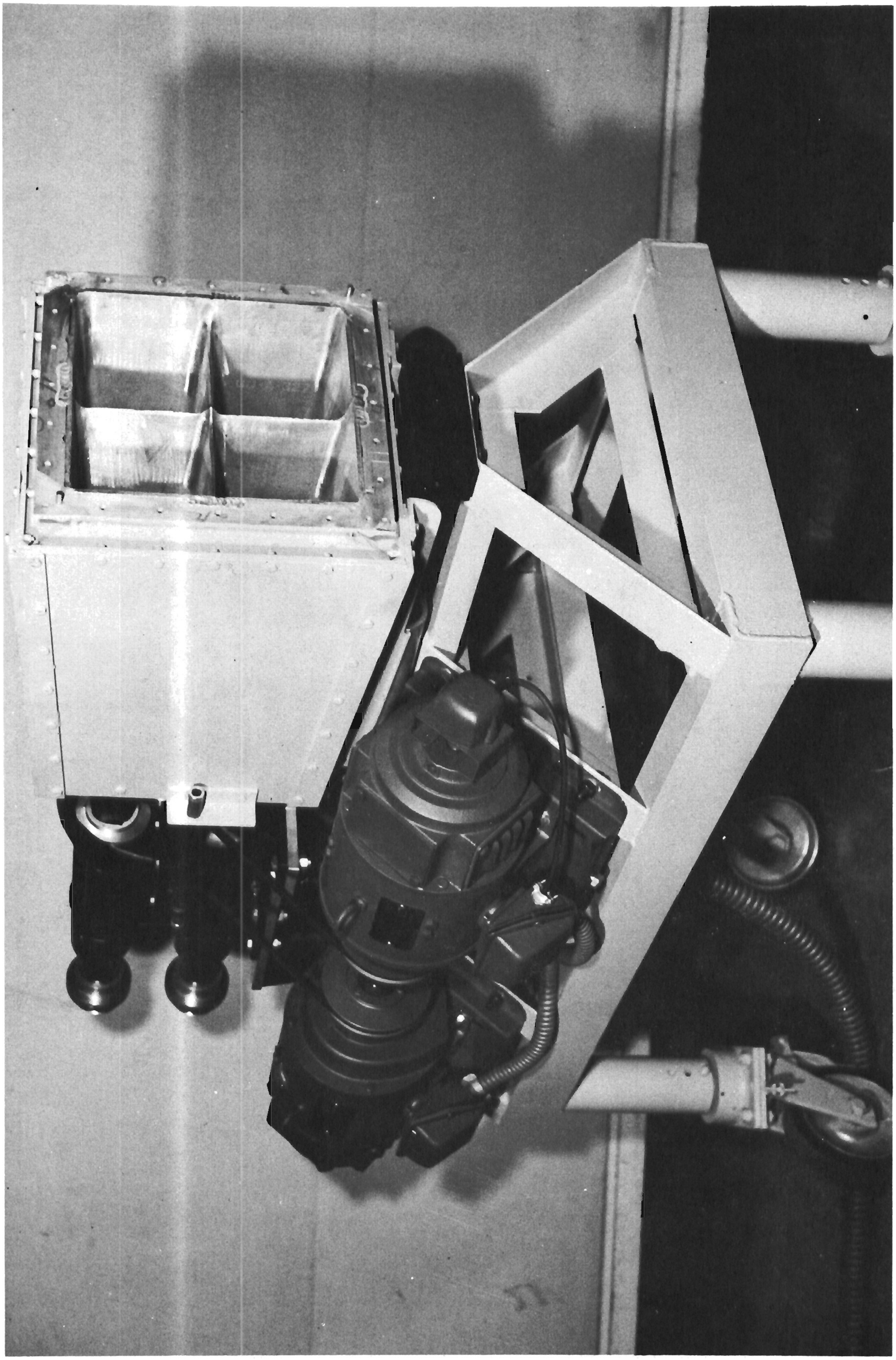


Figure 10. Mouth of First Horn Section

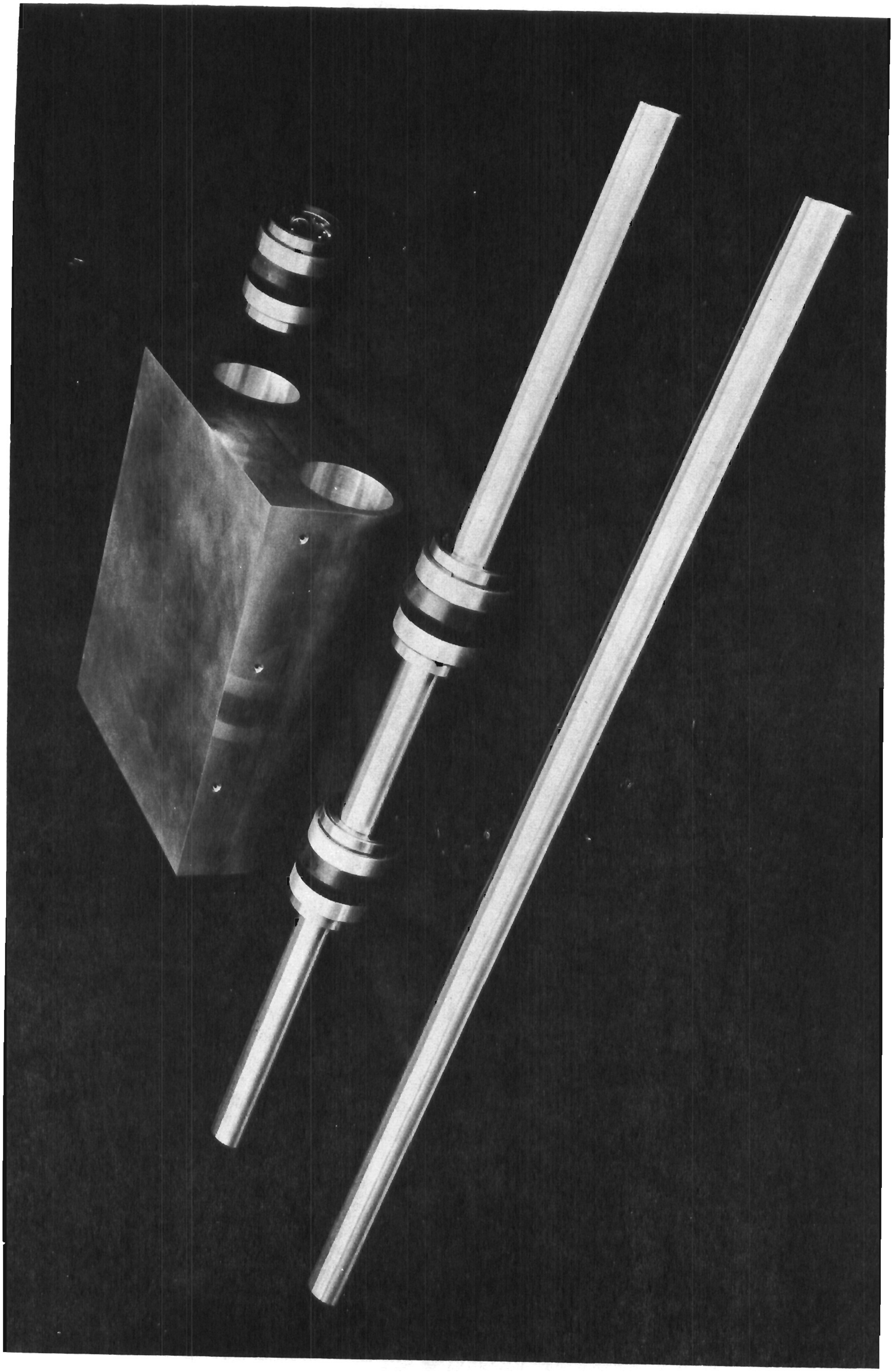


Figure 11. Carriage for First Horn Section - Shafts, Bushings, and Housing

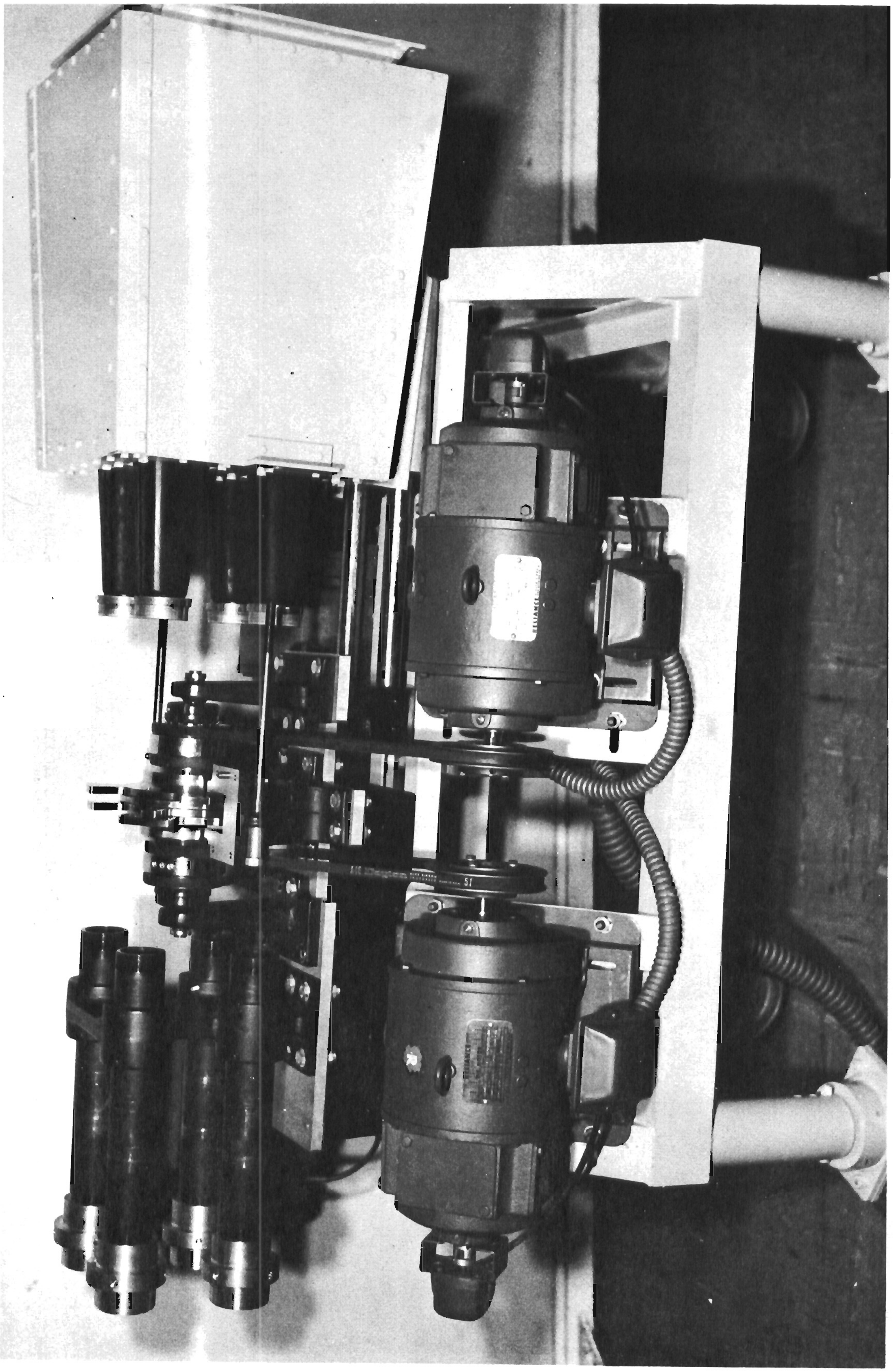


Figure 12. Siren with First Horn Section and Air Inlets - First Horn Pulled Forward

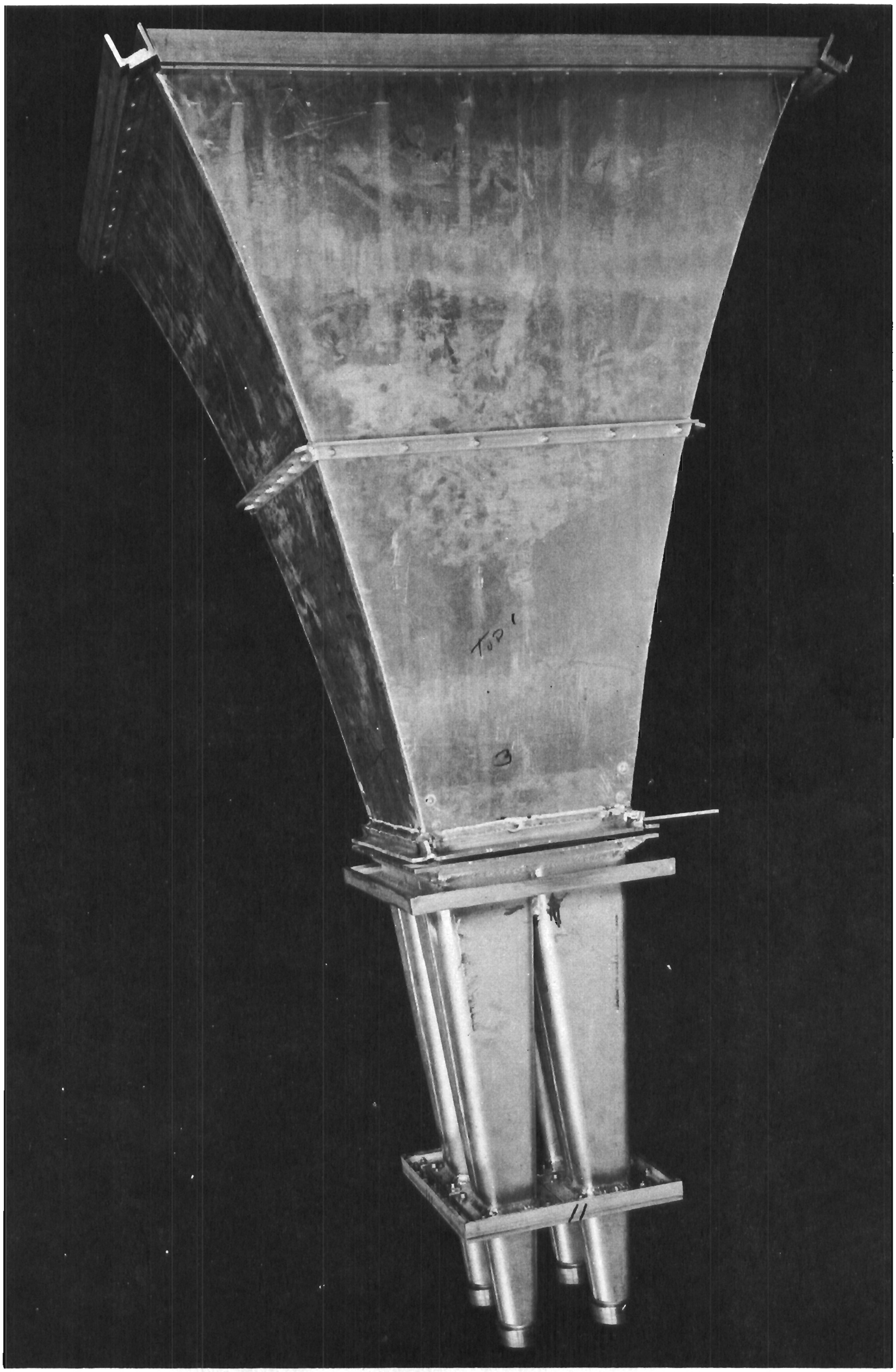
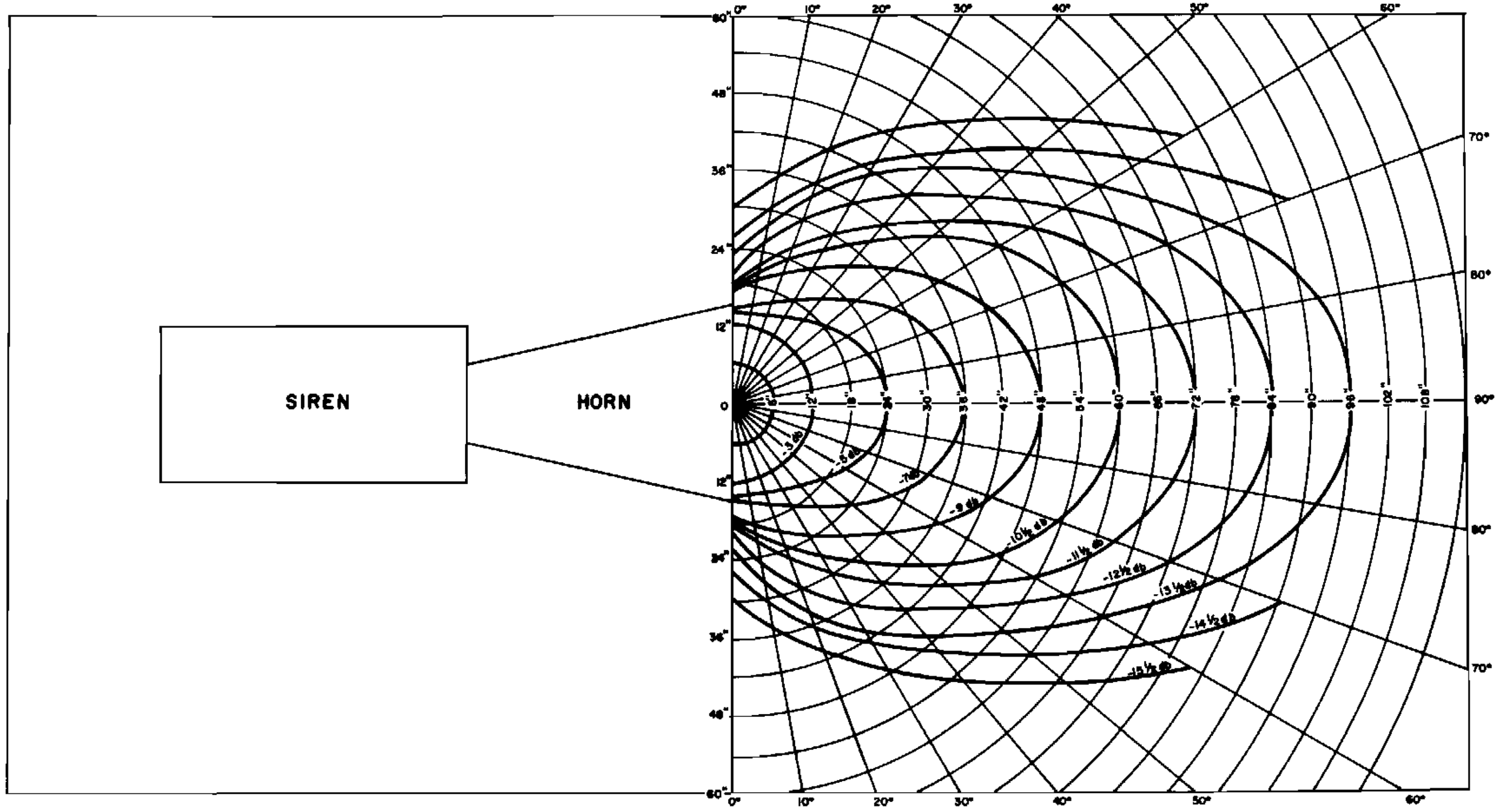


Figure 13. Horn Network - Inner Shell

CHARACTERISTIC	RANGE
FREQUENCY RANGE	40-16,000 CPS
SOUND POWER LEVEL re: 10^{-13} WATTS	15,000 WATTS
RMS SOUND PRESSURE LEVEL re: 0.0002 dynes/cm^2	172 db 11x11 INCH TEST SECTION
	165 db 37 x 29 INCH HORN MOUTH
AIR SUPPLY	10,000 CFM 50 PSIG
DRIVE SYSTEM	4-2 H P DC MOTORS
HORN, LARGE HORN, SMALL	115 CPS CUTOFF FREQUENCY 500 CPS CUTOFF FREQUENCY
TEST CHAMBER MAX REVERBERATION TIME	2.2 SEC

Figure 14. Facility Operating Characteristics



POWER PATTERN

Figure 15. Overall Sound Pressure Level Distribution - Semi-Progressive Waves (Top View)

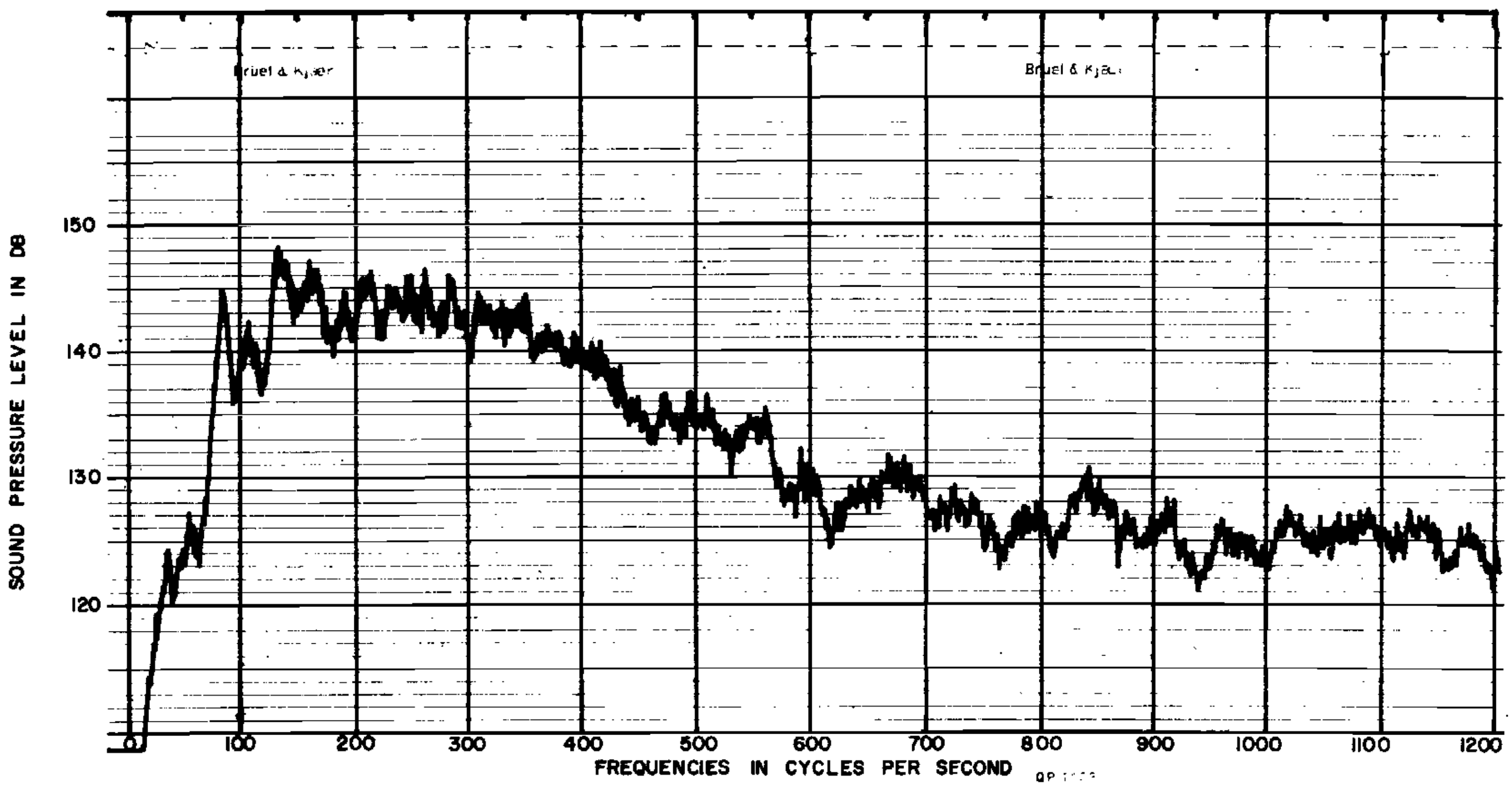


Figure 16. Narrow-Band Spectrum at Large Horn Mouth; Modulating Rotor Speeds; Reverberant Room; Three Air Inlets; No Rotor Housing

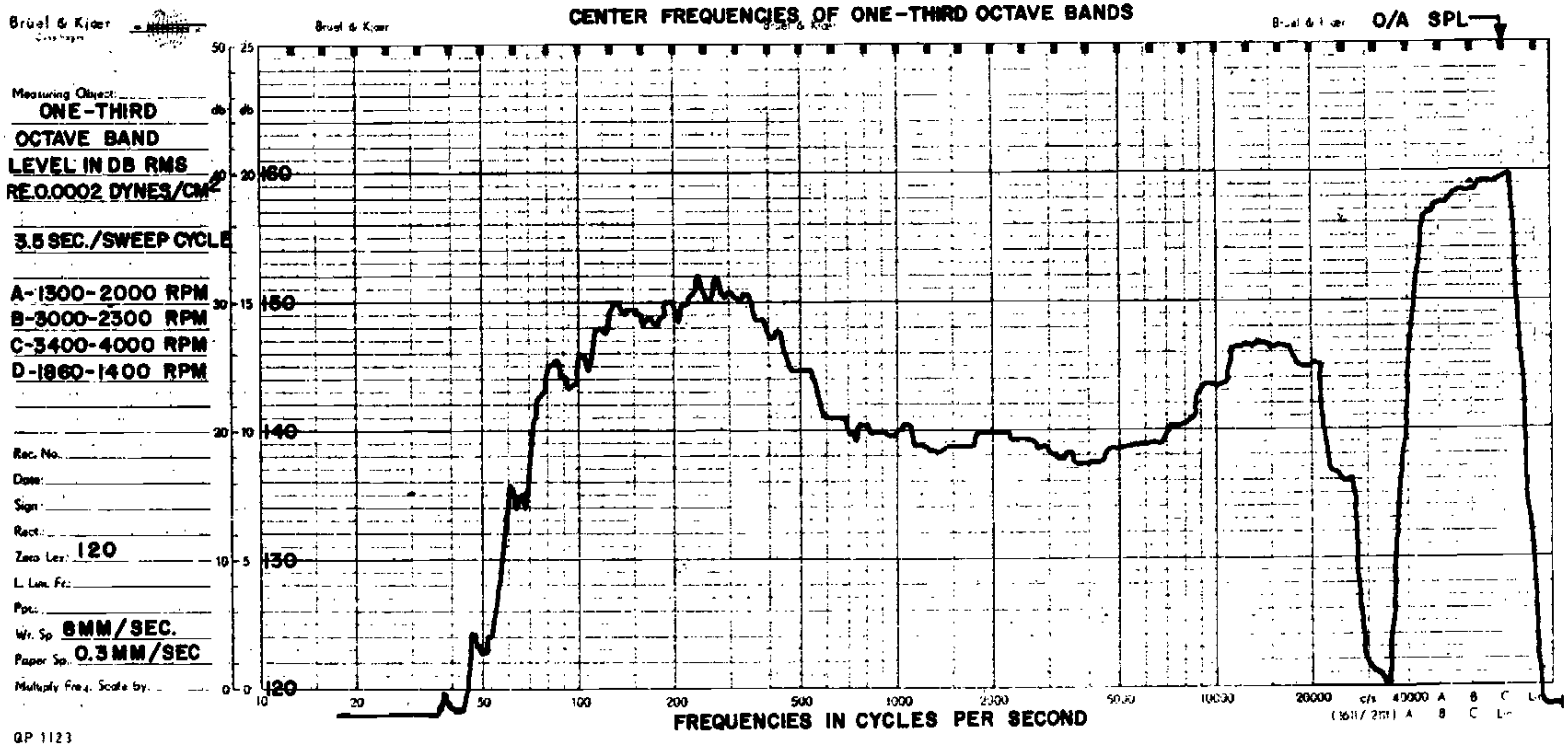


Figure 17. One-Third Octave-Band Spectrum at Large Horn Mouth; Modulating Rotor Speeds; Reverberant Room; Three Air Inlets; No Rotor Housing

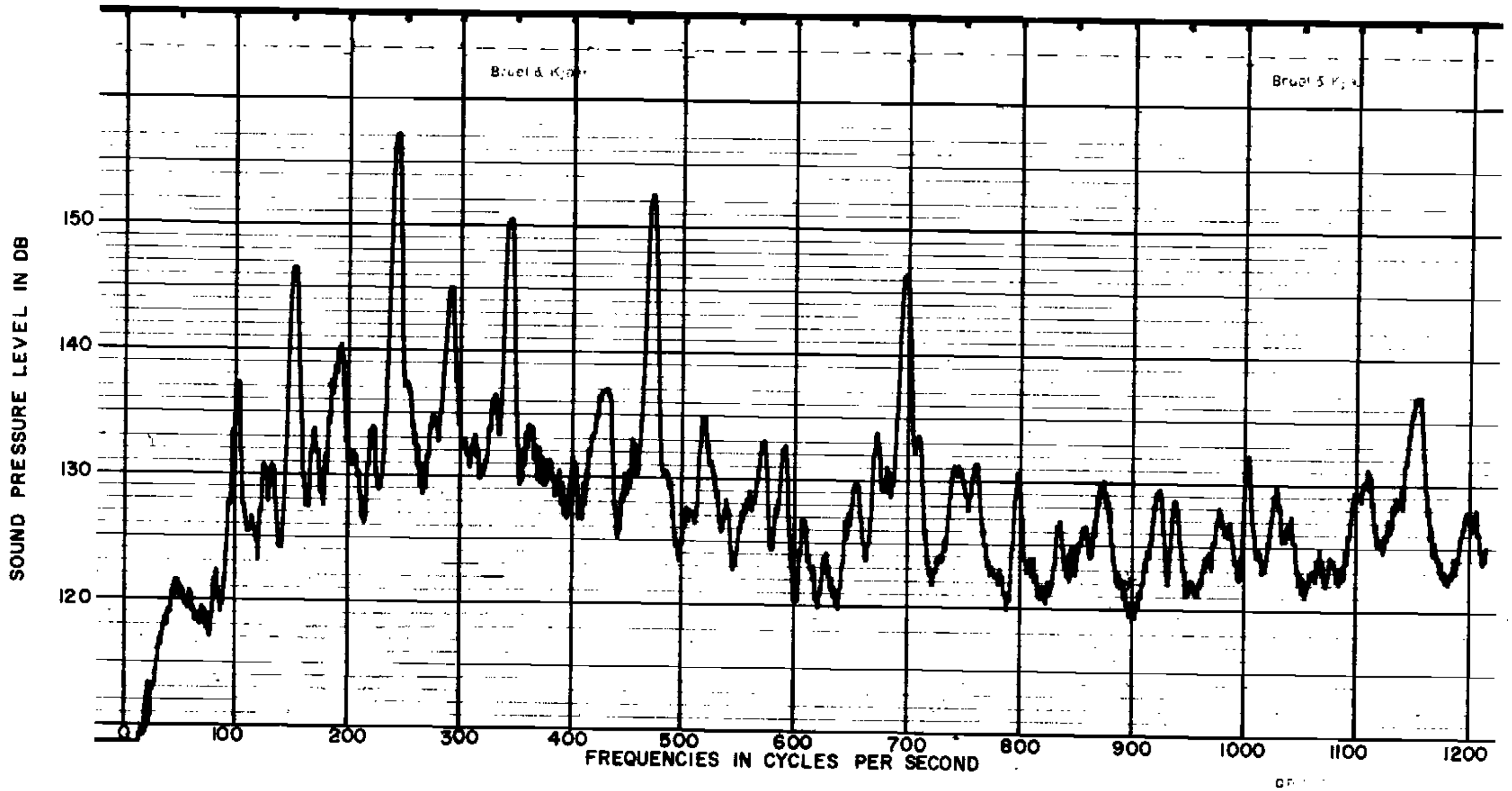


Figure 18. Narrow-Band Spectrum at Large Horn Mouth; Constant Rotor Speeds; Reverberant Room; Four Air Inlets; With Rotor Housing

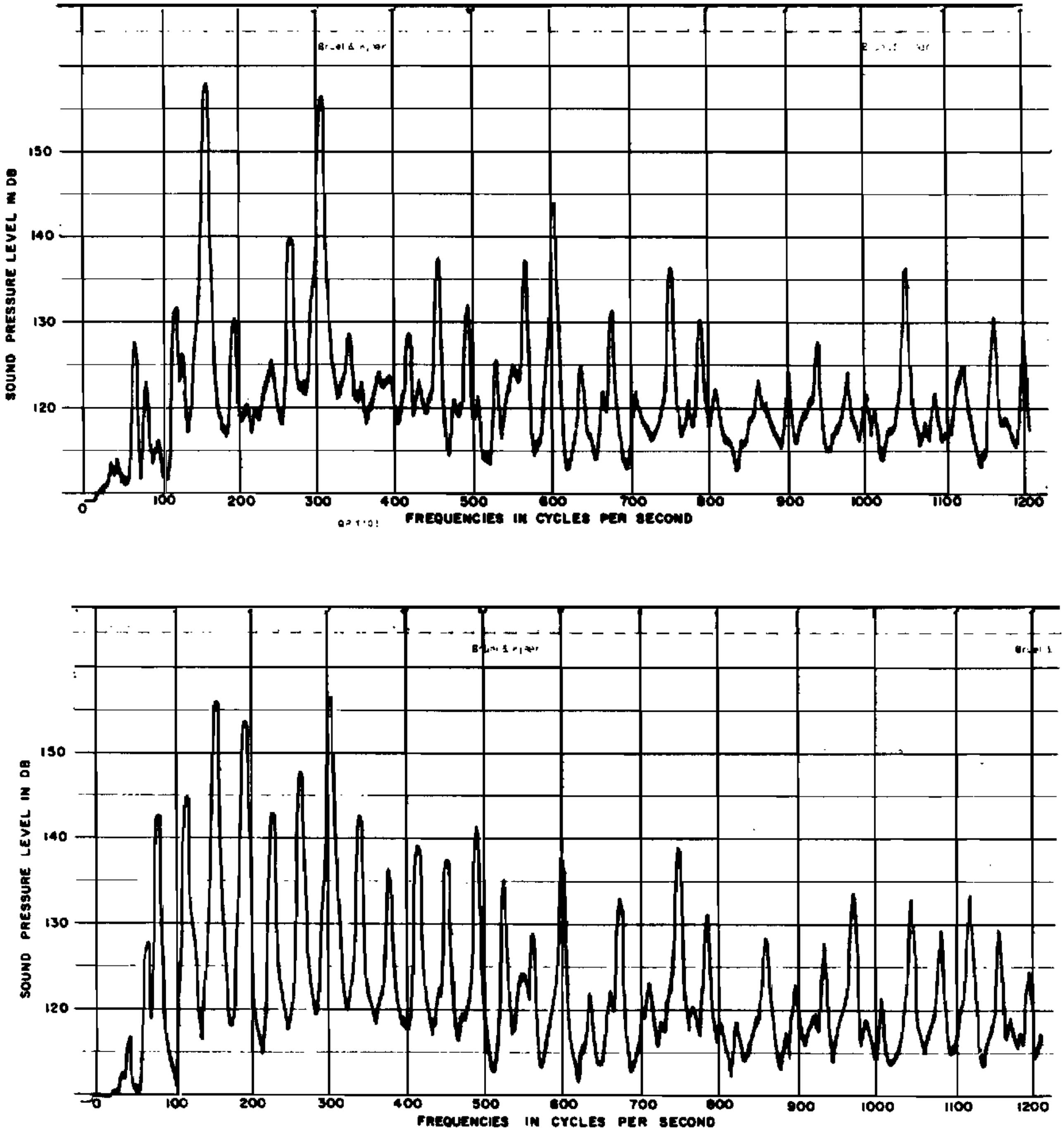


Figure 19. Narrow-Band Spectra at Large Horn Mouth; Single Rotor; Reverberant Room; Top - Four Air Inlets; Bottom - Three Air Inlets

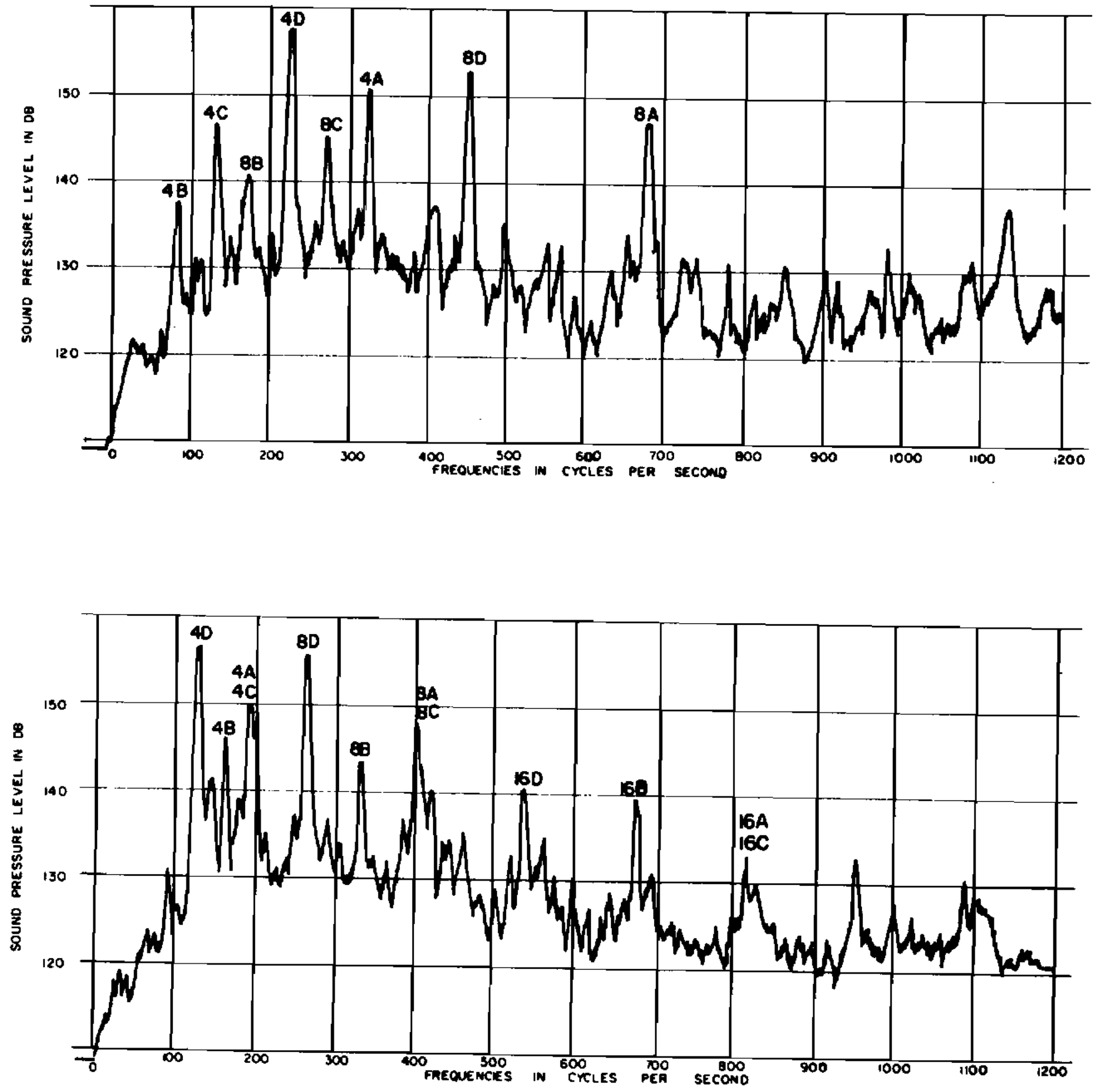


Figure 20. Narrow-Band Spectra at Large Horn Mouth; Constant Rotor Speeds; Reverberant Room; Three Air Inlets; Top - With Rotor Housing; Bottom - No Rotor Housing

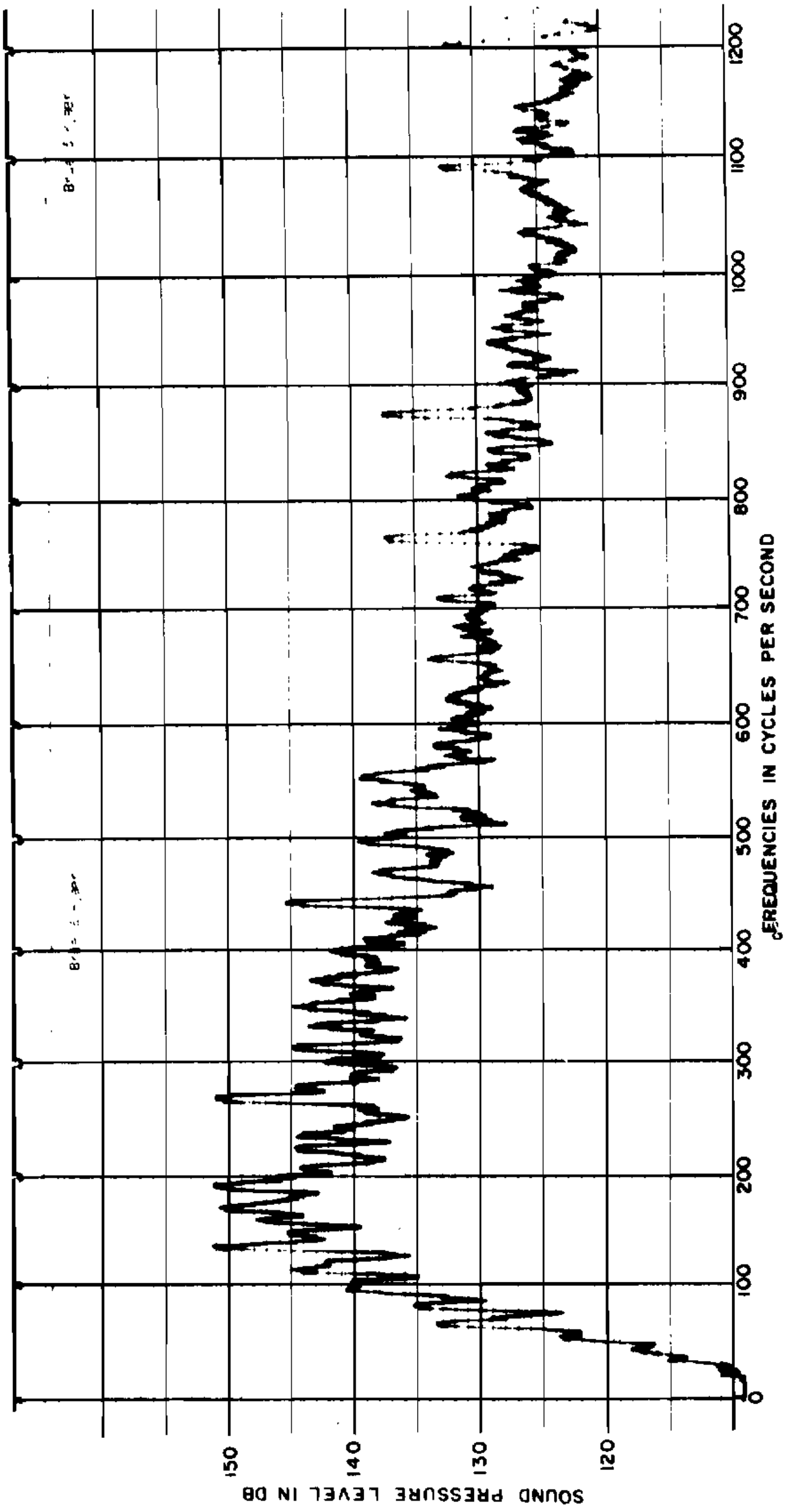
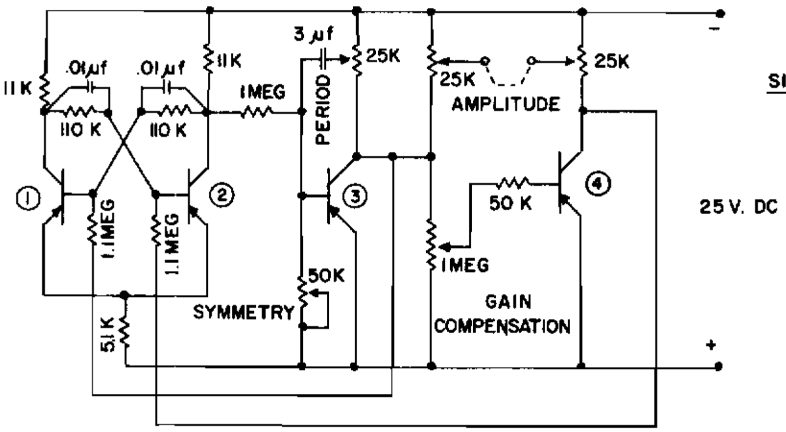
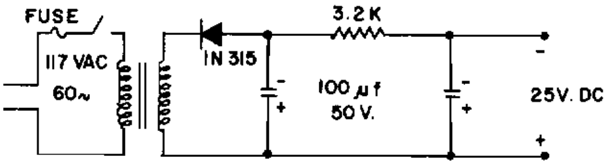


Figure 21. Narrow-Band Spectrum at Large Horn Mouth; Constant Rotor Speeds; Reverberant Room; Three Air Inlets; No Rotor Housing; Speed Ratios Based on 4th Root of 2



SIREN SWEEP SCHEMATIC

ALL TRANSISTORS 2N 404
ALL RESISTORS $\frac{1}{2}$ WATT 5%



SIREN SWEEP POWER SUPPLY SCHEMATIC

NOTES:

1. ONE SIREN SWEEP CIRCUIT AND ONE SIREN SWEEP POWER SUPPLY ARE USED FOR EACH ROTOR.

2. EACH ROTOR SWEEP AND CONTROLLER ARE ELECTRICALLY SEPARATED. DO NOT MAKE ANY ELECTRICAL CONNECTIONS BETWEEN ANY SEPARATED CIRCUITS

3. DO NOT TRY TO MEASURE ANY CIRCUIT VOLTAGES WITH A POWER-LINE-CONNECTED METER WHILE SWEEP UNIT IS CONNECTED TO THE SIREN POWER RECTIFIER CONTROLLER.

4. THE 3µf CAPACITORS MUST HAVE LOW LEAKAGE. TANTALUM CAPACITORS ARE RECOMMENDED.

Figure 22. Schematic Diagram for Rotor Speed Modulation

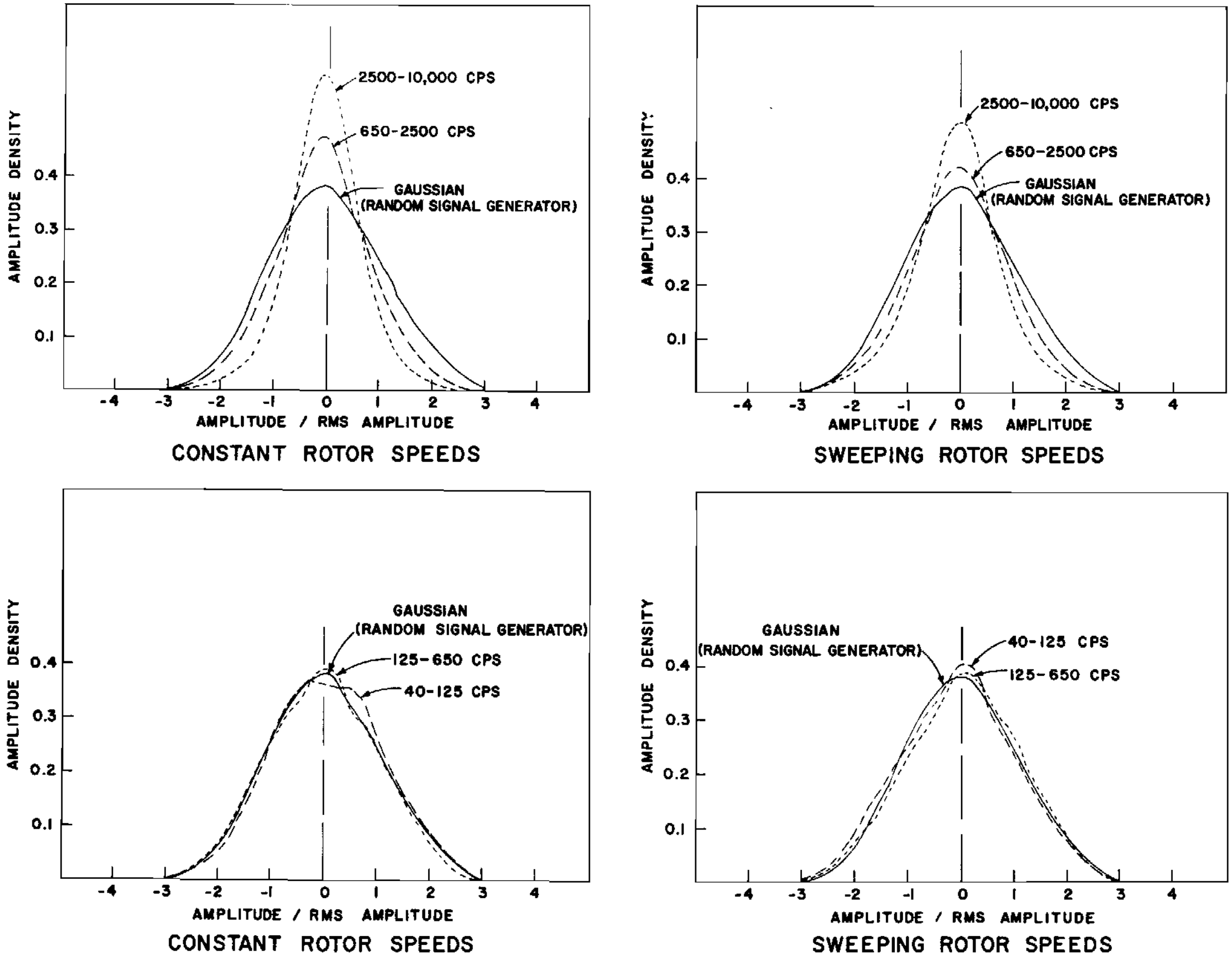
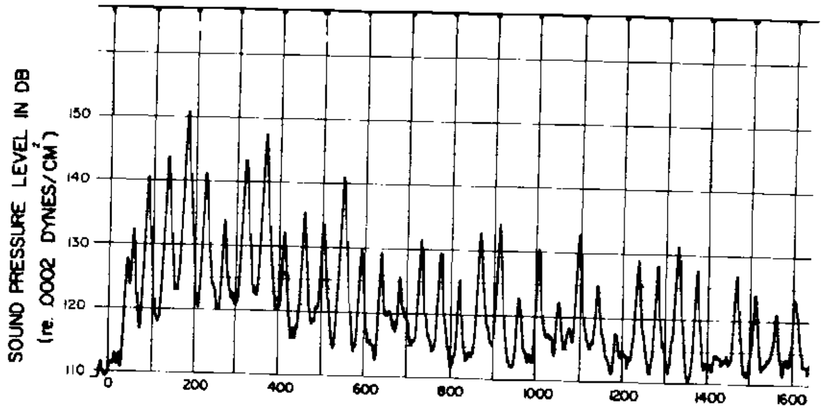
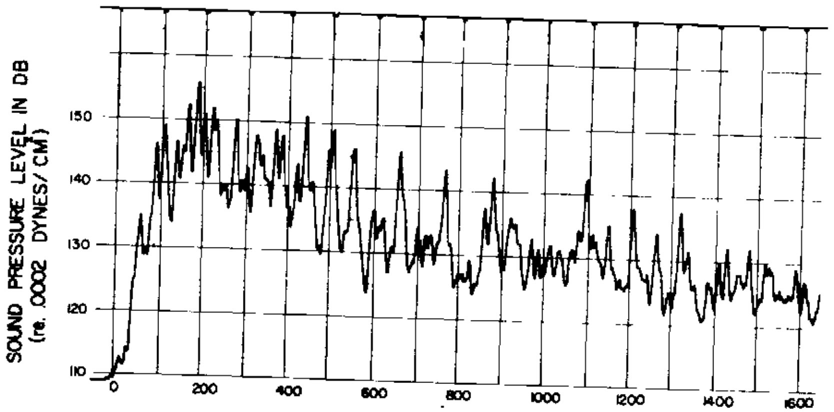


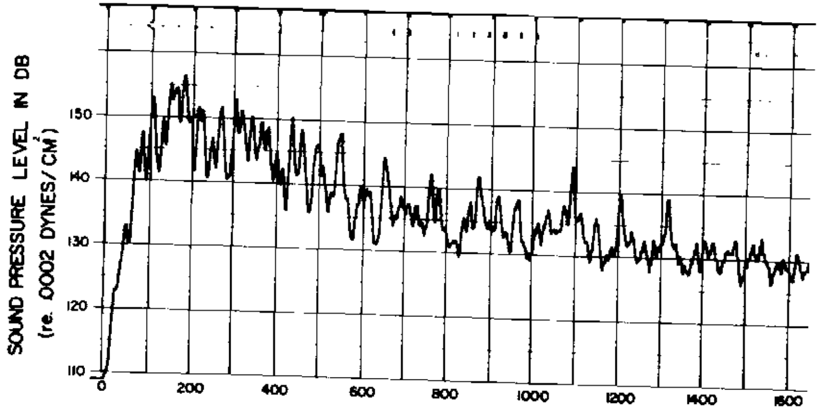
Figure 23. Amplitude Probability Density Function Comparison for Constant and Modulated Rotor Speeds



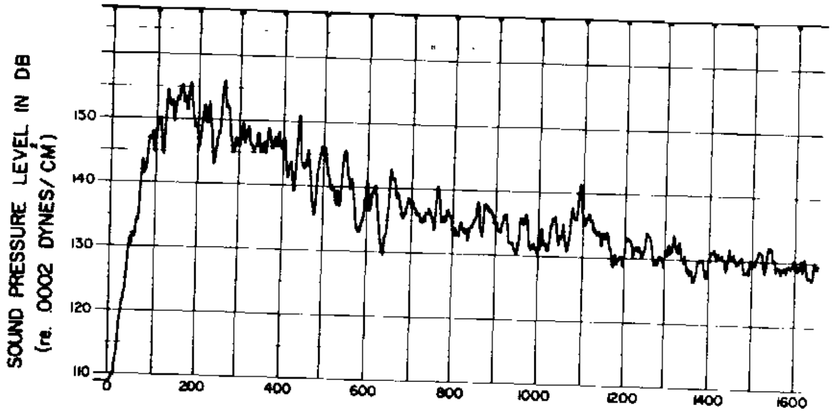
3.5 CPS BAND WIDTH FREQUENCY
ROTOR A=2760 RPM ROTOR B=0
ROTOR C=0 ROTOR D=0



3.5 CPS BAND WIDTH FREQUENCY
ROTOR A=2760 RPM ROTOR B=3270 RPM
ROTOR C=0 ROTOR D=0

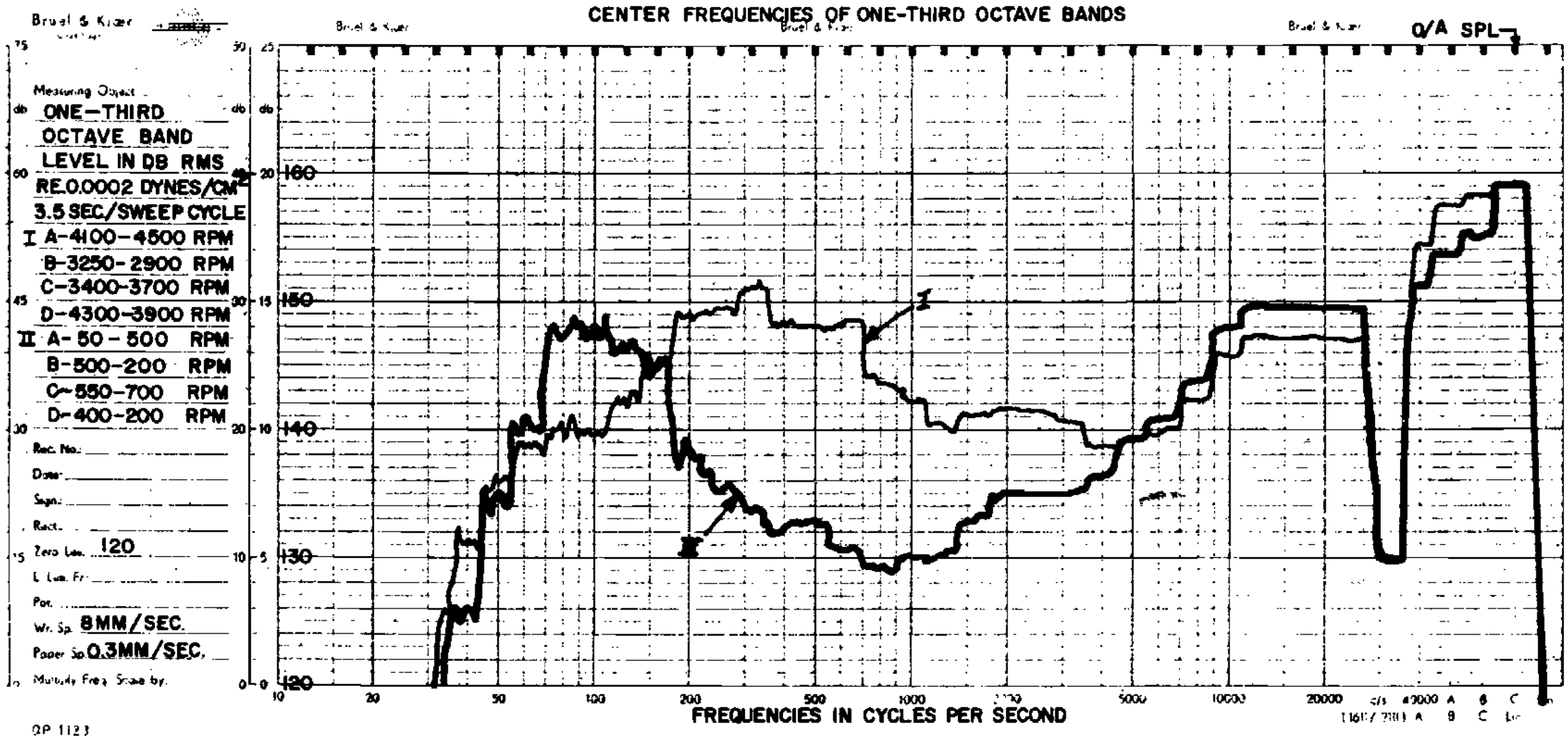


3.5 CPS BAND WIDTH FREQUENCY
ROTOR A=2760 RPM ROTOR B=3270 RPM
ROTOR C=2310 RPM ROTOR D=0



3.5 CPS BAND WIDTH FREQUENCY
ROTOR A=2760 RPM ROTOR B=3270 RPM
ROTOR C=2310 RPM ROTOR D=1950 RPM

Figure 24. Effect of Individual Rotors on Spectrum Continuity



BOTH CURVES MEASURED IN THE LARGE HORN MOUTH

Figure 25. Spectrum Shaping by Changing Rotor Speeds

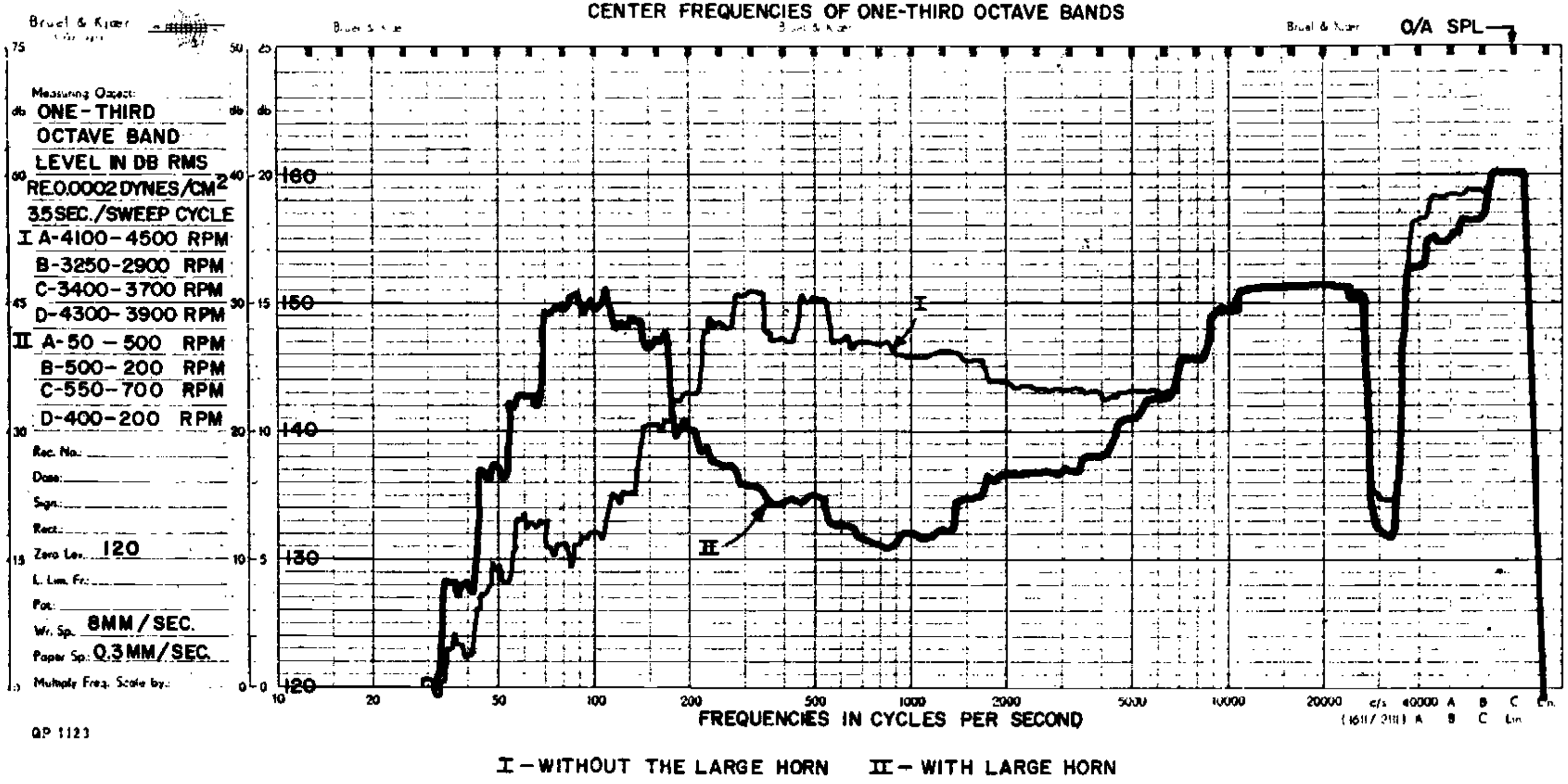
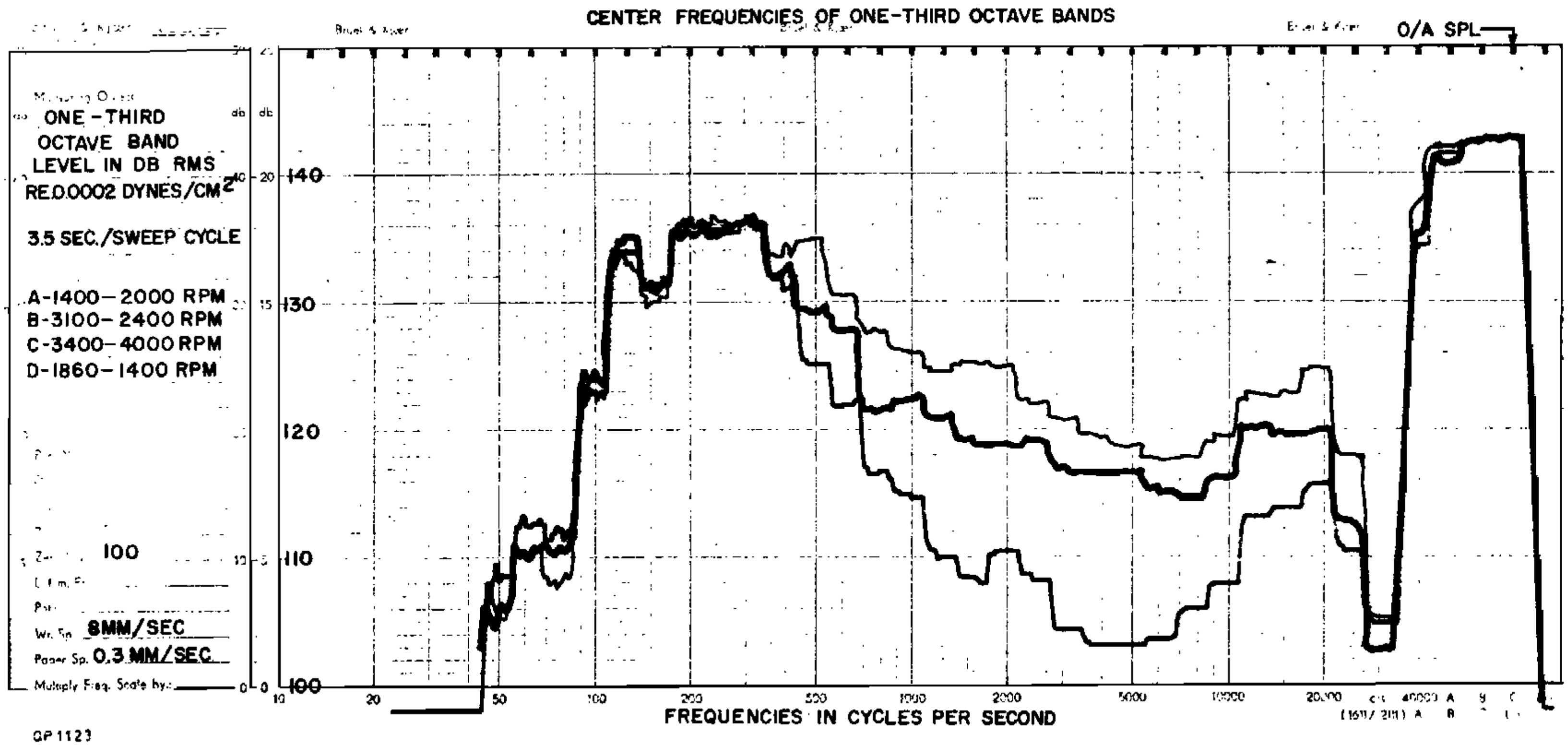


Figure 26. Spectrum Shaping by Changing Horn Section and Rotor Speeds



EACH CURVE REPRESENTS A DIFFERENT ABSORPTION CONFIGURATION

Figure 27. Spectrum Shaping by Absorption

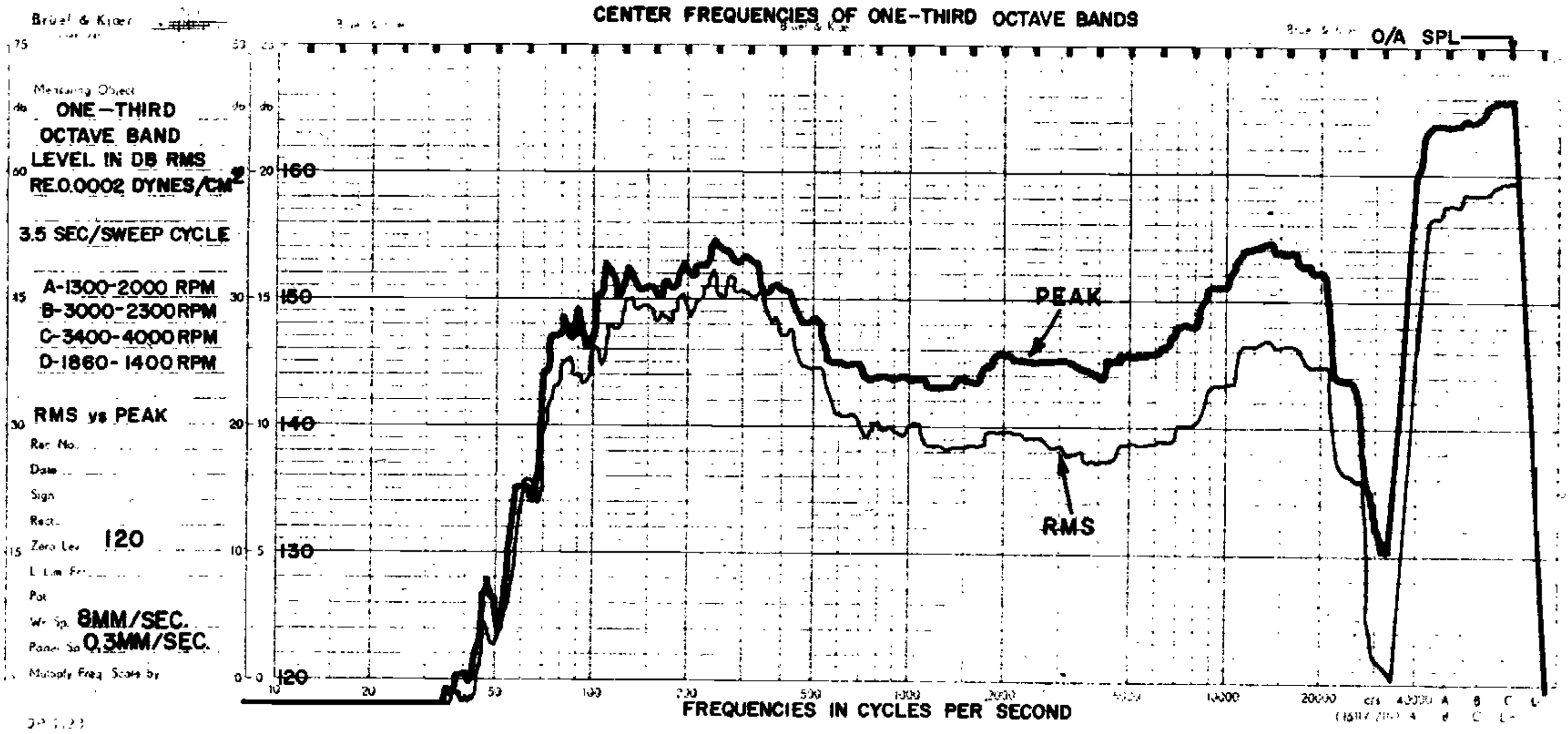


Figure 28. RMS Versus Peak Sound Pressure Levels; One-Third Octave-Band Analysis

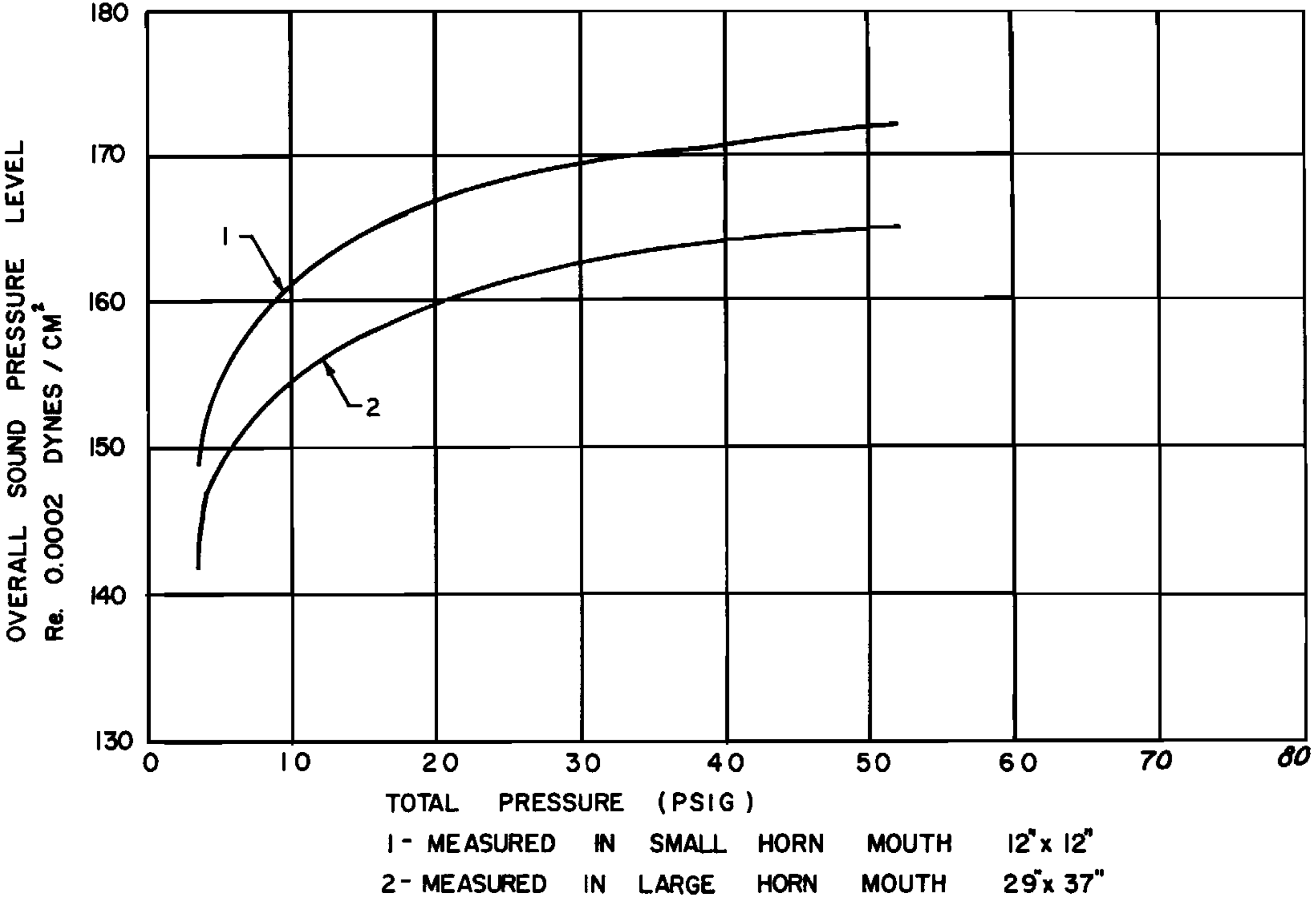


Figure 29. Overall Sound Pressure Level Versus Air Pressure

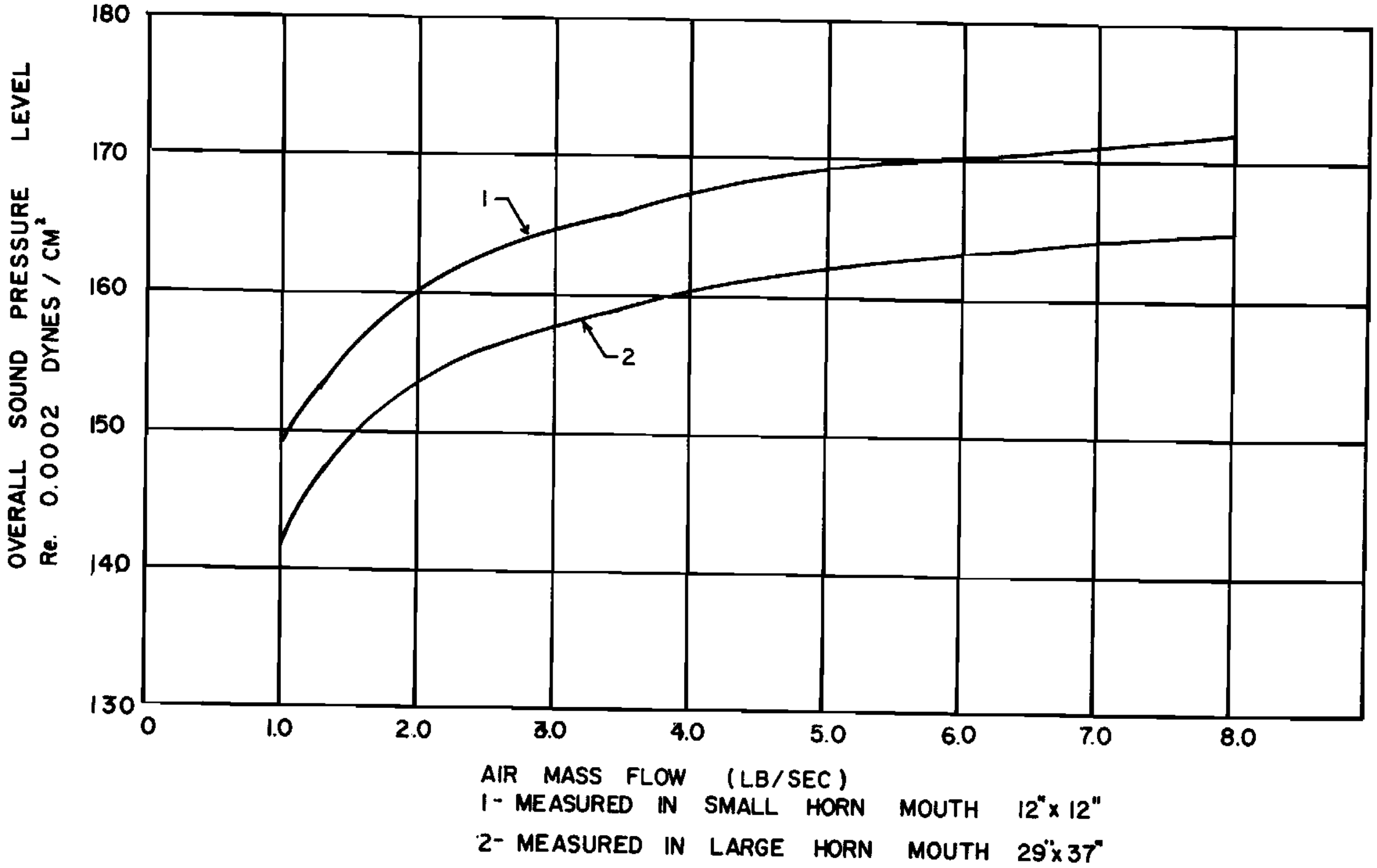


Figure 30. Overall Sound Pressure Level Versus Air Mass Flow

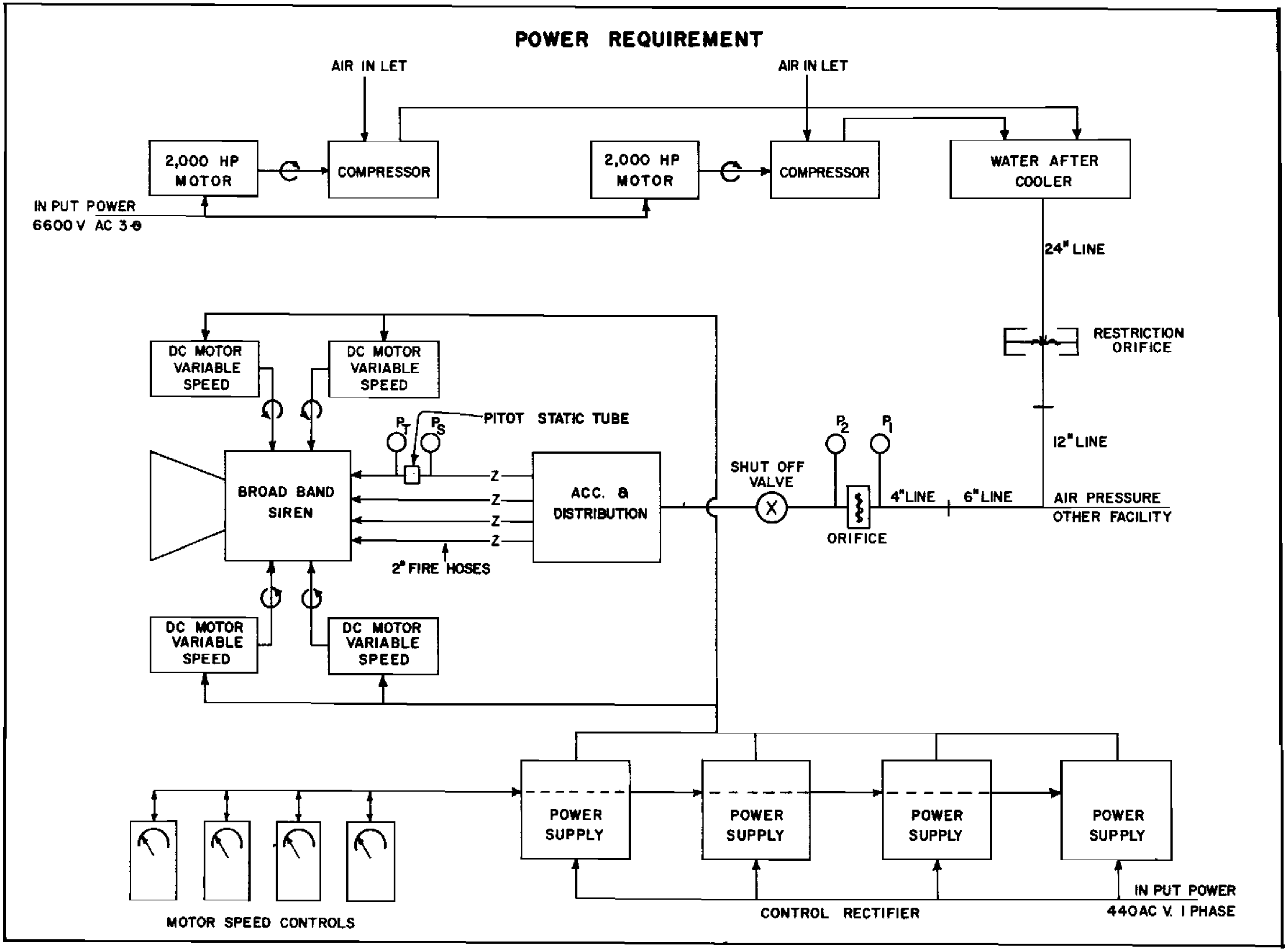


Figure 31. Wide Band Facility Power Schematic

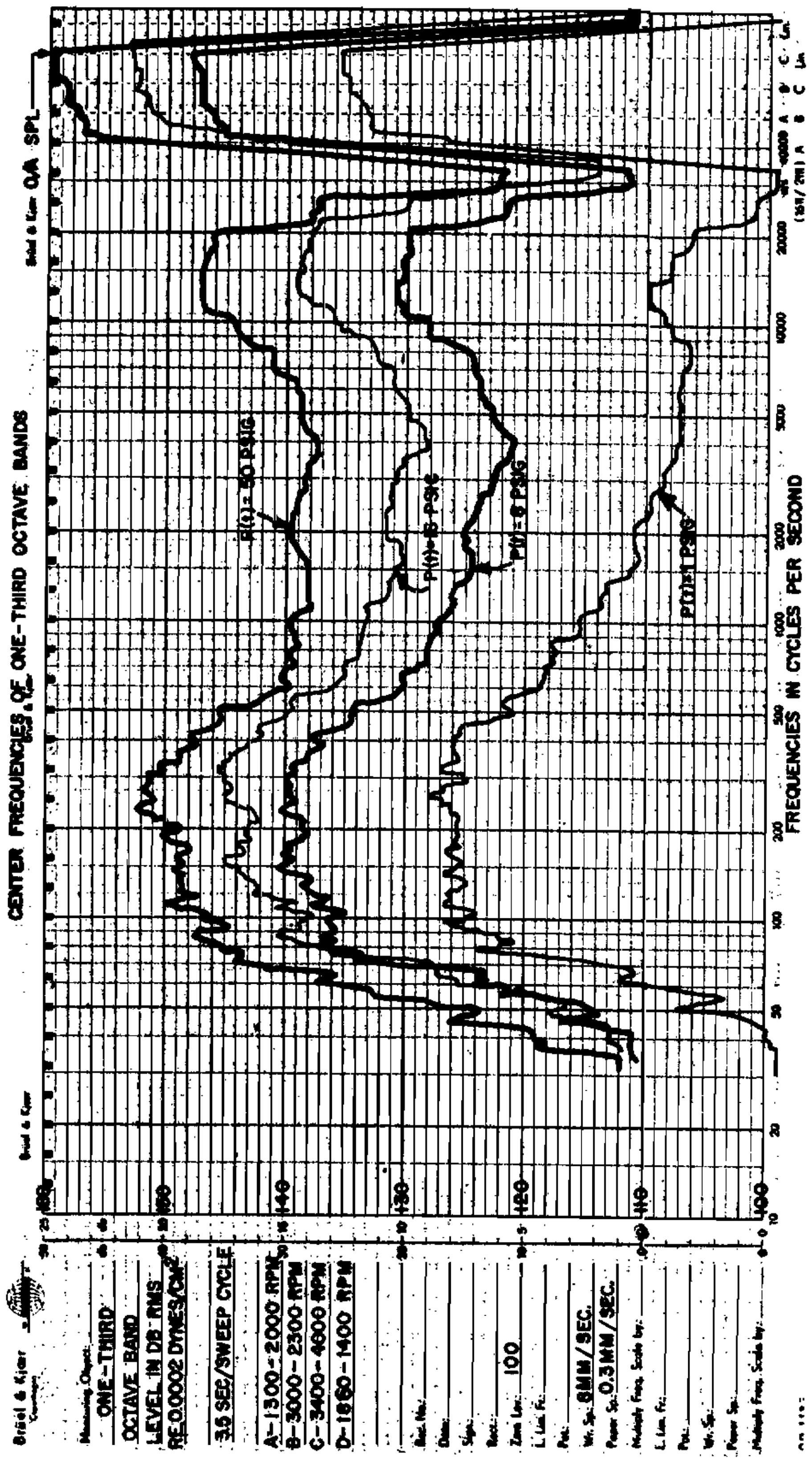


Figure 32. Effects of Pressure and Mass Flow on the Spectrum

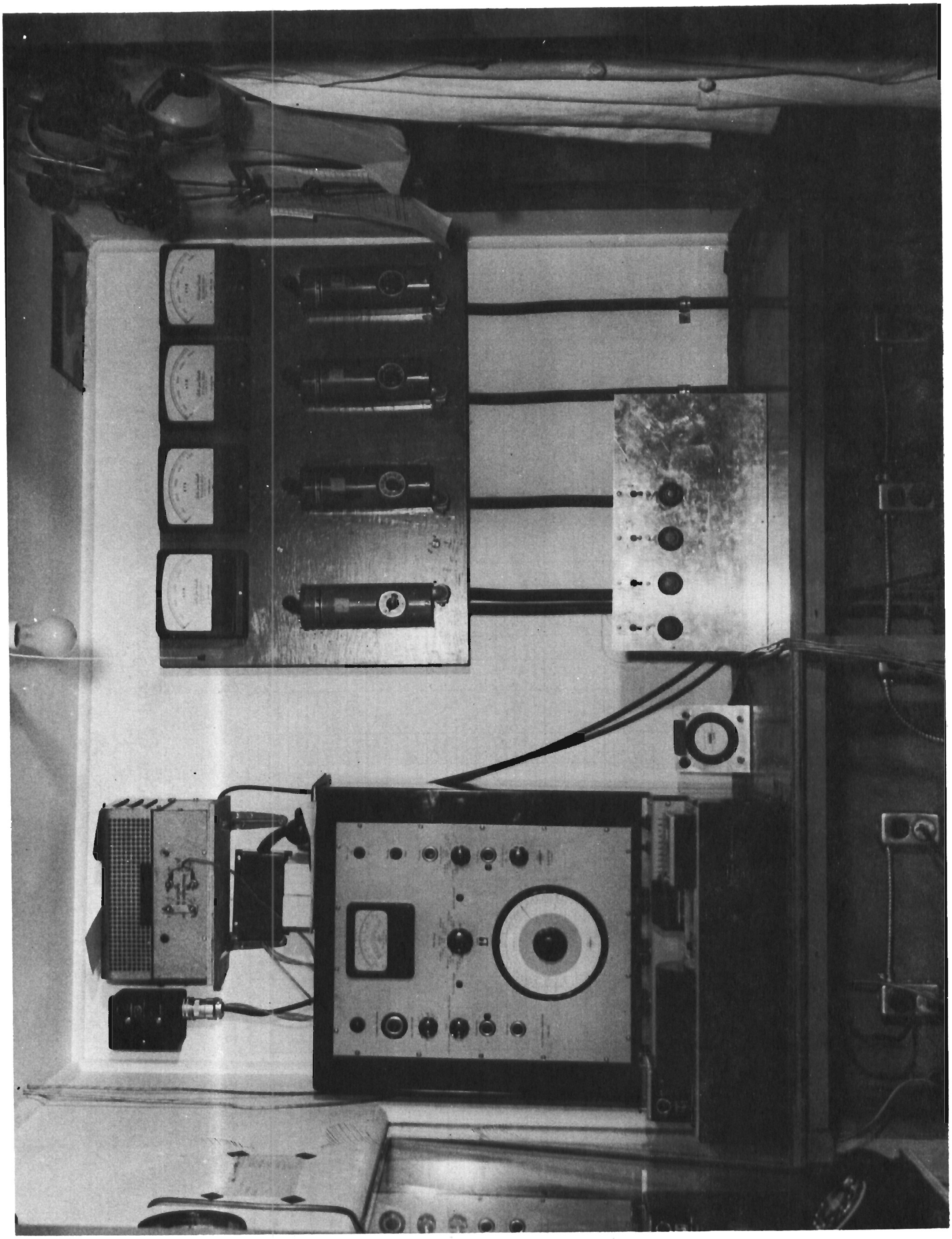


Figure 33. Instrumentation and Operating Station

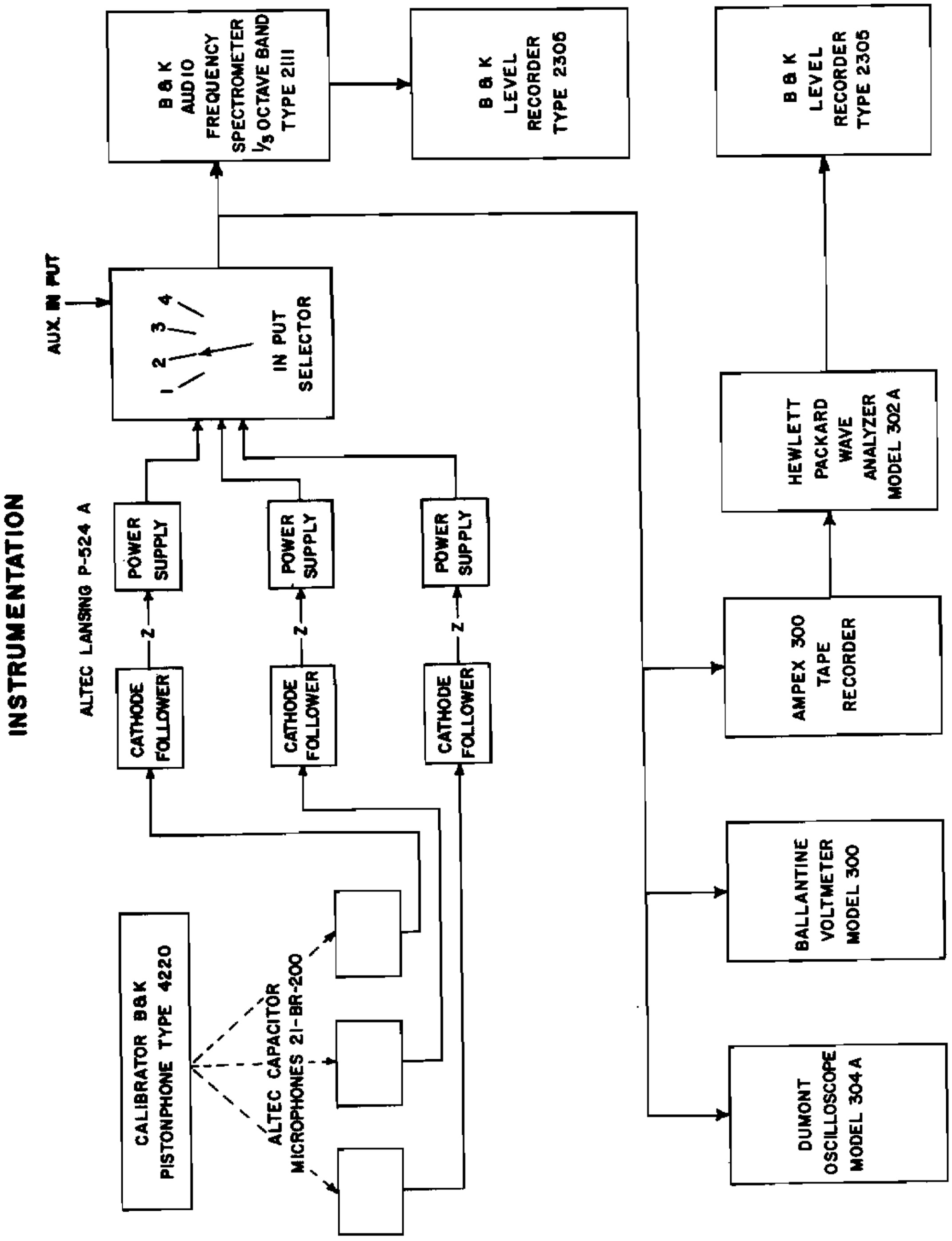


Figure 34. Noise Facility Instrumentation Schematic

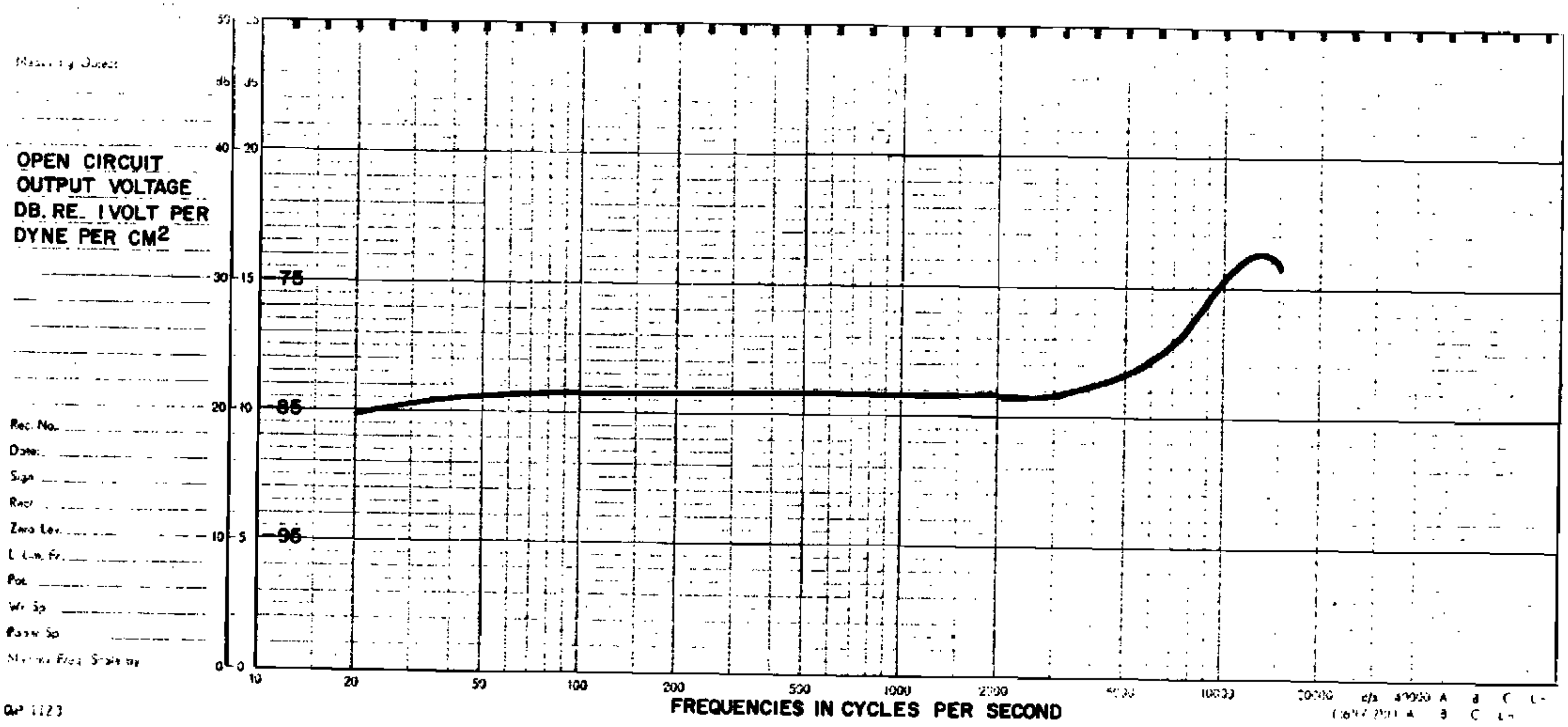


Figure 35. Typical Free Field Calibration Curve for 21 BR-200 Altec Microphone - Parallel Incidence

Unclassified
Security Classification

DOCUMENT CONTROL DATA - R&D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

1. ORIGINATING ACTIVITY *(Corporate author)*
Air Force Flight Dynamics Laboratory, Research and Technology Division, Air Force Systems Command, Wright-Patterson Air Force Base, Ohio

2a. REPORT SECURITY CLASSIFICATION
Unclassified

2b. GROUP

3. REPORT TITLE
Design and Performance of a 15 KC Wide Band Acoustic Facility

4. DESCRIPTIVE NOTES *(Type of report and inclusive dates)*
Final November 1960 to June 1964

5. AUTHOR(S) *(Last name, first name, initial)*
Hankel, Keith M.
Henderson, John P.

6. REPORT DATE
March 1966

7a. TOTAL NO. OF PAGES
60

7b. NO. OF REFS
11

8a. CONTRACT OR GRANT NO.

b. PROJECT NO.S. 1309; 4437

c. Task Nos. 130901; 443705

d.

9a. ORIGINATOR'S REPORT NUMBER(S)
AFFDL-TR-66-8

9b. OTHER REPORT NO(S) *(Any other numbers that may be assigned this report)*

10. AVAILABILITY/LIMITATION NOTICES
Distribution of this document is unlimited

11. SUPPLEMENTARY NOTES

12. SPONSORING MILITARY ACTIVITY
Air Force Flight Dynamics Laboratory, Research and Technology Division, Air Force Systems Command, Wright-Patterson AFB, Ohio

13. ABSTRACT

Details of the design and performance of a wide band, high intensity, acoustic test facility are presented. The wide band siren, horn network, sound isolation room, noise measurement and analysis instrumentation, input power requirements, and measured performance characteristics of the facility are described. The problem of the presence of several discrete frequency peaks in the spectrum of the original siren configuration is discussed along with techniques which were investigated to improve the spectrum. Frequency modulation of the rotor speeds is shown to result in a relatively smooth, continuous randon spectrum. The limited spectrum shaping capabilities of the siren are discussed. Recommendations are made for improvements that could be incorporated into future designs of sirens of this type.

DD FORM 1 JAN 64 1473

Unclassified
Security Classification

14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Wide Band Noise Source						
Sirens						
Acoustic Facility						

INSTRUCTIONS

1. ORIGINATING ACTIVITY: Enter the name and address of the contractor, subcontractor, grantee, Department of Defense activity or other organization *(corporate author)* issuing the report.

2*a*. REPORT SECURITY CLASSIFICATION: Enter the overall security classification of the report. Indicate whether "Restricted Data" is included. Marking is to be in accordance with appropriate security regulations.

2*b*. GROUP: Automatic downgrading is specified in DoD Directive 5200.10 and Armed Forces Industrial Manual. Enter the group number. Also, when applicable, show that optional markings have been used for Group 3 and Group 4 as authorized.

3. REPORT TITLE: Enter the complete report title in all capital letters. Titles in all cases should be unclassified. If a meaningful title cannot be selected without classification, show title classification in all capitals in parenthesis immediately following the title.

4. DESCRIPTIVE NOTES: If appropriate, enter the type of report, e.g., interim, progress, summary, annual, or final. Give the inclusive dates when a specific reporting period is covered.

5. AUTHOR(S): Enter the name(s) of author(s) as shown on or in the report. Enter last name, first name, middle initial. If military, show rank and branch of service. The name of the principal author is an absolute minimum requirement.

6. REPORT DATE: Enter the date of the report as day, month, year; or month, year. If more than one date appears on the report, use date of publication.

7*a*. TOTAL NUMBER OF PAGES: The total page count should follow normal pagination procedures, i.e., enter the number of pages containing information.

7*b*. NUMBER OF REFERENCES: Enter the total number of references cited in the report.

8*a*. CONTRACT OR GRANT NUMBER: If appropriate, enter the applicable number of the contract or grant under which the report was written.

8*b*, 8*c*, & 8*d*. PROJECT NUMBER: Enter the appropriate military department identification, such as project number, subproject number, system numbers, task number, etc.

9*a*. ORIGINATOR'S REPORT NUMBER(S): Enter the official report number by which the document will be identified and controlled by the originating activity. This number must be unique to this report.

9*b*. OTHER REPORT NUMBER(S): If the report has been assigned any other report numbers *(either by the originator or by the sponsor)*, also enter this number(s).

10. AVAILABILITY/LIMITATION NOTICES: Enter any limitations on further dissemination of the report, other than those imposed by security classification, using standard statements such as:

(1) "Qualified requesters may obtain copies of this report from DDC."

(2) "Foreign announcement and dissemination of this report by DDC is not authorized."

(3) "U. S. Government agencies may obtain copies of this report directly from DDC. Other qualified DDC users shall request through
_______________________________________."

(4) "U. S. military agencies may obtain copies of this report directly from DDC. Other qualified users shall request through
_______________________________________."

(5) "All distribution of this report is controlled. Qualified DDC users shall request through
_______________________________________."

If the report has been furnished to the Office of Technical Services, Department of Commerce, for sale to the public, indicate this fact and enter the price, if known.

11. SUPPLEMENTARY NOTES: Use for additional explanatory notes.

12. SPONSORING MILITARY ACTIVITY: Enter the name of the departmental project office or laboratory sponsoring *(paying for)* the research and development. Include address.

13. ABSTRACT: Enter an abstract giving a brief and factual summary of the document indicative of the report, even though it may also appear elsewhere in the body of the technical report. If additional space is required, a continuation sheet shall be attached.

It is highly desirable that the abstract of classified reports be unclassified. Each paragraph of the abstract shall end with an indication of the military security classification of the information in the paragraph, represented as *(TS)*, *(S)*, *(C)*, or *(U)*.

There is no limitation on the length of the abstract. However, the suggested length is from 150 to 225 words.

14. KEY WORDS: Key words are technically meaningful terms or short phrases that characterize a report and may be used as index entries for cataloging the report. Key words must be selected so that no security classification is required. Identifiers, such as equipment model designation, trade name, military project code name, geographic location, may be used as key words but will be followed by an indication of technical context. The assignment of links, rules, and weights is optional.