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The development of a method for the determination  
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Reynolds, John Lynn.

Massachusetts Institute of Technology

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**THE DEVELOPMENT OF A METHOD  
FOR THE DETERMINATION OF ACOUSTIC  
CHARACTERISTICS OF VENTILATING FANS**

—————♦♦♦—————  
**JOHN L. REYNOLDS  
KENNETH E. WILSON, JR.**

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THE DEVELOPMENT OF A METHOD FOR THE DETERMINATION  
OF ACOUSTIC CHARACTERISTICS OF VENTILATING FANS

by

John L. Reynolds, Lieutenant (junior grade), U.S. Navy.  
B.S., U.S. Naval Academy, 1946.

Kenneth E. Wilson, Jr., Lieutenant (junior grade), U.S. Navy.  
B.S., U.S. Naval Academy, 1946.

Submitted in Partial Fulfillment  
of the Requirements for the  
Degree of Naval Engineer  
from the  
Massachusetts Institute of Technology  
1952

Authors

Department of Naval Architecture and Marine Engineering

May 16, 1952





ABSTRACT

## Title:-

THE DEVELOPMENT OF A METHOD FOR THE DETERMINATION OF ACOUSTIC CHARACTERISTICS OF VENTILATING FANS

## Authors:-

John L. Reynolds, Lieutenant (junior grade), U.S. Navy.  
B. S., U.S. Naval Academy, 1946.

Kenneth E. Wilson, Jr., Lieutenant (junior grade), U.S. Navy.  
B.S., U.S. Naval Academy, 1946.

Submitted in Partial Fulfillment of the Requirements for the Degree of Naval Engineer from the Massachusetts Institute of Technology, 1952.

The primary object of this series of tests was to develop a method by which the acoustic characteristics (frequency spectra and sound output) of axial-flow ventilating fans can be accurately and completely determined. In the process of this development, it was hoped that information could be obtained which would make it possible to calculate the sound power output of fans of known mechanical power and design characteristics.

Two fans of different capacities (500 and 1500 cfm) were tested at various speeds with and without moderate back pressure. The test setup consisted of a duct system of heavy construction into which the fan noise was directed. The duct

ABSTRACT

Title-

THE DEVELOPMENT OF A METHOD FOR THE DETERMINATION OF ACOUSTIC CHARACTERISTICS BY VELOCITY PLOTS

Author-

John L. Berman, Lieutenant (Junior Grade), U.S. Navy,  
U.S. Naval Academy, 1946.  
Edward M. Wilson, Lt., Lieutenant (Junior Grade), U.S. Navy,  
U.S. Naval Academy, 1946.Abstract in Vertical Alignment of the Department of the  
Office of Naval Research from the Massachusetts Institute of  
Technology, 1955.

The primary object of this series of tests was to develop a method by which the acoustic characteristics (frequency spectra and sound output) of actual-flow venturi-like forms can be determined and accurately determined. In the process of this development, it was hoped that information could be obtained which would make it possible to calculate the sound power output of forms of known mechanical power and design characteristics.

The tests of different geometries (500 and 1500 cm)

were carried out in a reverberant chamber and without reference to pressure. The test setup consisted of a tank of water connected into which the test noise was directed. The test

was terminated in an exponential horn to prevent acoustic reflections and standing waves in the measuring duct. Absolute sound-pressure level was measured in the duct using a miniature condenser microphone inserted therein and shielded by a windscreen. The output of the microphone was amplified and measured directly on a vacuum-tube voltmeter for overall levels. The noise spectra for the different conditions of speed and back pressure were obtained using a one-third octave-band filter set with band-center frequencies between 100 and 10,000 cps.

The data obtained for the smaller of the two fans indicated high sound-pressure levels in the frequency bands containing the fundamental and fourth harmonic of the blade frequency. As frequency increased, a general trend toward lower spectrum levels was observed. The same general trends were found to exist in the spectra of the larger fan; but, probably due to compressibility effects, the fundamental and harmonic peaks were not clearly observable. From the data for overall sound-pressure level, a formula was derived that gave power levels in close agreement with those measured for both fans above a speed of about 2600 RPM.

The consistency of data and conformity with theory were used as a basis for determining the adequacy of this new test method. The general agreement of trends

was determined in an experimental form to several acoustic

oscillations and standing waves in the resonating duct.

The acoustic pressure level was measured in the duct

using a miniature condenser microphone connected therein

and isolated by a windshield. The output of the micro-

phone was amplified and measured directly on a vacuum-

tube voltmeter for pressure levels. The noise spectra

for the different conditions of speed and back pressure

were obtained using a one-third octave-band filter and

with band-center frequencies between 100 and 10,000 cps.

The data obtained for the smaller of the two

ducts indicated high sound-pressure levels in the frequency

bands containing the fundamental and fourth harmonics of

the duct frequency. In frequency bands near a general

level below lower spectrum levels was observed. The

same general trends were found to exist in the spectra

of the larger duct but probably due to compressibility

effects, the fundamental and harmonic levels were not

clearly observed. From the data for overall sound-power

level, a trend was noticed that gave lower levels

in those apparatus with those passages for both diameters

a speed of about 500 ft/min.

The consistency of data and methods with

theory was used as a basis for determining the accuracy

of this test method. The general agreement of trends

among all data taken, some agreement with axial-flow compressor theory, and satisfactory repeatability of data all indicated that the method is adequate to accomplish its proposed function. The satisfactory conformity of measured with computed overall power levels indicated that the empirical formula derived is of correct form.

Further work is essential in connection with the ventilating system source analysis. This work should include tests of axial-flow fans of other sizes and designs to substantiate or correct the findings of this investigation.

Thesis Supervisor:-

Leo L. Beranek

Title:-

Associate Professor  
Electrical Engineering

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Cambridge, Massachusetts

May 16, 1952

Secretary of the Faculty  
Massachusetts Institute of Technology  
Cambridge, Massachusetts

Dear Sir:-

In accordance with the requirements for the  
Degree of Naval Engineer, we submit a thesis entitled:-  
"The Development of a Method for the Determination of  
Acoustic Characteristics of Ventilating Fans".

Respectfully yours,

William B. Reynolds,  
Lieutenant (junior grade),

Renneth E. Wilson, Jr.  
Lieutenant (junior grade),  
U. S. Navy





ACKNOWLEDGEMENTS

The authors wish to acknowledge their indebtedness to Professor Leo L. Beranek, Technical Director of the Acoustics Laboratory, Massachusetts Institute of Technology, for his continual help and criticism in the course of this investigation. We also thank Mr. Henry C. Lang for his advice in all phases of the work, Mr. George Kamperman for invaluable assistance in setting up the measuring system, and Miss Lydia Bonazzoli for the accomplishment of many little things throughout this study, and her typing of this final report. Finally, we thank everyone connected with the Acoustics Laboratory for his patience and help, without which the completion of this investigation would have been impossible.

CONCLUSIONS

The authors wish to acknowledge their indebtedness to Professor Lee J. Haycock, Technical Director of the Acoustic Laboratory, Massachusetts Institute of Technology, for his constant help and criticism in the course of this investigation. We also thank Mr. Harry C. Lang for his advice in the choice of the word, Dr. George Sauer for valuable assistance in setting up the recording system, and Miss Lydia Gombosi for the acknowledgment of many little things throughout this study, and her typing of this final report. Finally, we thank everyone connected with the Acoustic Laboratory for his patience and help, without which the completion of this investigation would have been impossible.

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## I. INTRODUCTION

Aboard ship, in office buildings, and in industrial plants, one of the important sources of noise is the ventilating system. If complete acoustic characteristics of these systems are determined, it is possible to make accurate predictions of noise levels in spaces supplied by these systems. Design engineers can then design the duct system mechanically and acoustically to attain a specified noise level in the ventilated spaces.

This study was the first step in a proposed acoustical analysis of ventilating systems. The ventilating system analysis will be divided into a study of fans, duct systems, and duct terminations. This investigation pertains to the first phase of the problem, the determination of the characteristics of axial-flow fans as acoustic power sources.

It was the specific purpose of this investigation to determine the adequacy of a proposed method for obtaining the acoustic characteristics of ventilating fans. The major consideration was the quality of the data obtained using the proposed test set-up. The quality of the data was judged by comparing the data obtained for the fans tested, under varying conditions of speed and back pressure.

## I. INTRODUCTION

It is well known that the design of a ventilation system is one of the important aspects of noise control. The ventilation system, if properly designed, can reduce the noise level in the occupied space. The design of such systems is based on the prediction of noise levels in spaces supplied by these systems. Design engineers can then design the duct system accordingly and economically to obtain a specific noise level in the occupied space.

This study was the first step in a proposed systematic analysis of ventilation systems. The ventilation system analysis will be divided into a study of duct, duct system, and duct termination. This investigation begins at the first phase of the problem, the determination of the characteristics of air-flow in ducts as acoustic power sources.

It was the specific purpose of this investigation to determine the adequacy of a proposed method for obtaining the acoustic characteristics of ventilating fans. The major consideration was the quality of the data obtained using the proposed test set-up. The quality of the data was judged in comparing the data obtained for the fans tested under various operating conditions of speed and back pressure.

The method presently used by the Navy of testing ventilating fans is felt to be somewhat limited in its scope and in the application of the data which can be obtained. This method, now in use at the Material Laboratory, New York Naval Shipyard, consists of sound measurements around the fan casing for varying conditions of back pressure and at constant speed. The measurements are made in an acoustically treated room (not an anechoic chamber), the acoustic qualities of which would be difficult or impossible to duplicate. No information is obtained on the frequency spectrum of the fan, and the noise transmitted down a duct cannot be determined. Therefore, these data cannot be used to assist in the prediction of noise levels in spaces supplied by a duct system. Its only value lies in making possible the intercomparison of various fans of the same type.

The proposed method for determining the sound-power output of a ventilating fan consisted, basically, of measuring the sound-power level in a duct connected to the fan exhaust. Reflections and standing waves are prevented in the measuring duct by terminating the duct in an exponential horn.

Various tests were made to determine the adequacy of the experimental duct system. It was found that sound-



The method generally used by the way of testing

ventilating fans is that to be somewhat limited in its

scope and in the application of the data which are

obtained. This method, used in some of the technical papers

issued, has been largely confined to sound measure-

ments around the fan casing for varying conditions of

load pressure and at constant speed. The measurements

are made in an acoustically treated room just to maintain

quietness. The acoustic qualities of noise would be different

in different conditions. An indicator is obtained

on the frequency spectrum of the fan, and the noise level

is noted down a great amount of material. Therefore, these

data cannot be used to assist in the prediction of noise

levels in spaces supplied by a duct system. The only

method is to make possible the inter-comparison of various

fans of the same type.

The proposed method for determining the sound-

power output of a ventilating fan described, basically,

is measuring the sound-power level in a duct connected

to the fan exhaust. Reflections and standing waves are

prevented by the mounting duct of reverberating the duct

in an anechoic room.

Further tests were made to determine the accuracy

of the experimental duct system. It was found that sound-

pressure levels remained essentially constant as the microphone was moved axially in the duct, although the sound-pressure level was changed by radial movement of the microphone in the measuring duct. A windscreen was placed around the microphone in all tests to minimize the effect of wind noise on measured sound-pressure levels.

Two fans of different capacities were tested in this investigation. At various speeds and back pressures, frequency spectrum and overall sound-pressure levels were recorded. These data were studied to determine the appearance of high levels at the blade frequency fundamental and its harmonics. The overall levels for the two fans were compared, and an empirical formula was derived whereby overall power level could be predicted for a given fan operating at a certain speed.

The data obtained was consistent, and it was believed to be of a type which will be of value to the design engineer. Trends followed those expected in most cases, and the data compared favorably with results of tests for noise levels produced by airplane propellers. It is therefore felt that the proposed test method is a good one, and it warrants further investigation and exploitation.

The first level is the level of the system as a whole. This level is concerned with the overall structure and organization of the system. It is at this level that the system is defined and its purpose is stated. The second level is the level of the subsystems. This level is concerned with the structure and organization of the individual subsystems. It is at this level that the subsystems are defined and their functions are described. The third level is the level of the components. This level is concerned with the structure and organization of the individual components. It is at this level that the components are defined and their functions are described.

The fourth level is the level of the data. This level is concerned with the structure and organization of the data. It is at this level that the data is defined and its format is described. The fifth level is the level of the control. This level is concerned with the structure and organization of the control. It is at this level that the control is defined and its functions are described. The sixth level is the level of the interface. This level is concerned with the structure and organization of the interface. It is at this level that the interface is defined and its functions are described. The seventh level is the level of the user. This level is concerned with the structure and organization of the user. It is at this level that the user is defined and his functions are described.

The eighth level is the level of the environment. This level is concerned with the structure and organization of the environment. It is at this level that the environment is defined and its functions are described. The ninth level is the level of the system. This level is concerned with the structure and organization of the system. It is at this level that the system is defined and its functions are described. The tenth level is the level of the user. This level is concerned with the structure and organization of the user. It is at this level that the user is defined and his functions are described.

## II. PROCEDURE

Since the purpose of this thesis is to determine an adequate and meaningful method of obtaining the sound-power output of ventilating fans, much time was spent in arriving at the method of testing the fans and in setting up the apparatus and equipment to be used in the fan tests. It thus seems fitting that the equipment and the test method employed should be described in detail.

### A. Test Setup

#### 1. Duct System (Fig. 1)

a. Measuring Duct - It was decided that sound-pressure level measurements should be made by placing a microphone in a duct which extended from the exhaust end of the fan. Measurements were to be made at a point about 8 feet from the fan. Since it was planned to test three fans, the  $A\frac{1}{2}$ ,  $Al\frac{1}{2}$ , and A3, the duct was designed with the same inside diameter as that of the largest fan, that is,  $21\frac{1}{8}$  inches. This duct was 5 feet in length, of circular cross-section, and of  $\frac{1}{16}$  -inch galvanized steel construction. In testing the two smaller fans, three-foot circular sections of

II. PROCEDURE

Since the purpose of this study is to

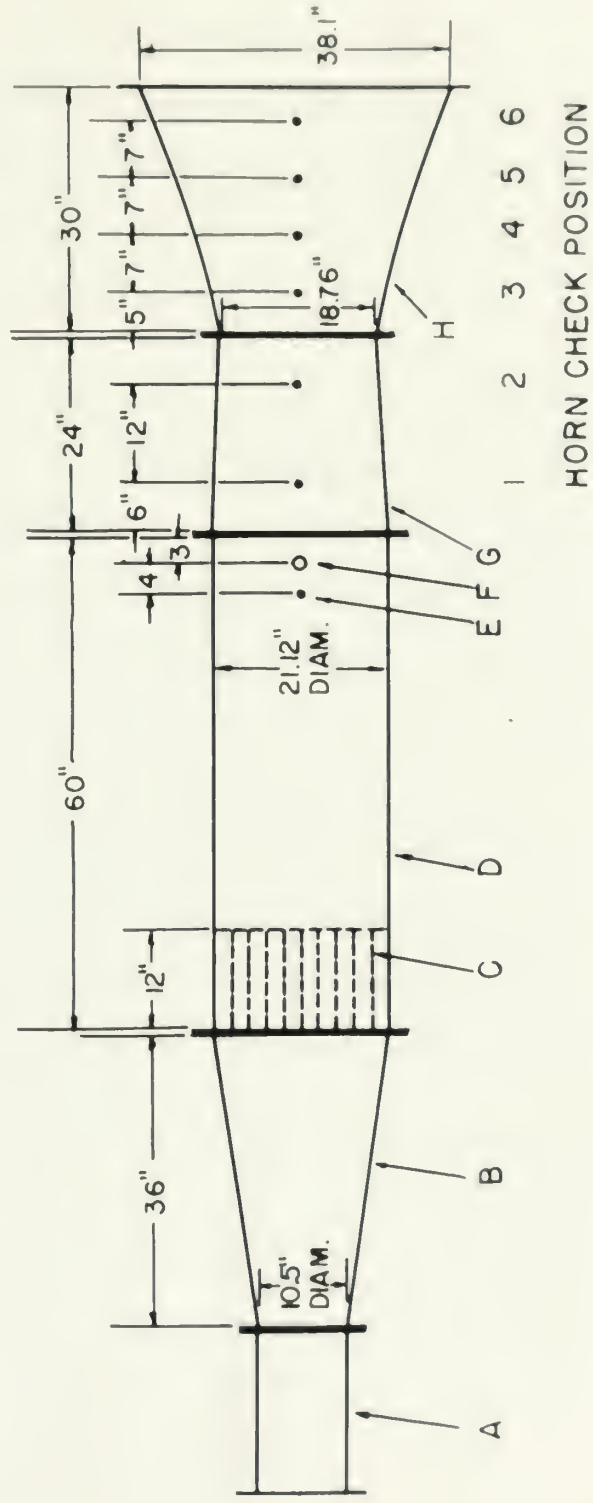
determine an accurate and reliable method of  
obtaining the sound-power output of vibrating fans,  
more time was spent in arriving at the method of  
testing the fans and in setting up the apparatus and  
equipment to be used in the test. It was found  
that this the equipment and the test method employed  
should be described in detail.

A. Test Setup

1. Test System (Fig. 1)

A. Sounding Box - It was desired that  
sound-pressure level measurements should be made by  
placing a microphone in a duct which extended from the  
exhaust end of the fan. Measurements were to be made  
at a point about 5 feet from the fan. Since it was  
planned to test three fans, the  $\frac{1}{2}$ ,  $1\frac{1}{2}$ , and  $2\frac{1}{2}$  fan  
ducts were designed with the same inside diameter as that  
of the largest fan, that is,  $1\frac{1}{2}$  inches. This duct  
was 2 feet in length, of circular cross-section, and  
of  $\frac{1}{16}$ -inch galvanized steel construction. In testing  
the two smaller fans, three-foot diameter sections of

- |                                      |                       |
|--------------------------------------|-----------------------|
| A- FAN A <sup>1</sup> / <sub>2</sub> | E- MANOMETER FIXTURE  |
| B- EXPANSION SECTION                 | F- MICROPHONE OPENING |
| C- STRAIGHTENING VANES               | G- ADAPTER            |
| D- MEASURING SECTION                 | H- EXPONENTIAL HORN   |



FAN AND DUCT SYSTEM

FIGURE I



increasing area were placed between the fans and the five-foot measuring duct. Nine straightening vanes were inserted in the duct about 4 feet from the fan in order to reduce the turbulence of air flow. A manometer connection and microphone opening were placed in the measuring duct as shown in Fig. 1.

b. Exponential Horn - In order to prevent wave reflections and resulting standing waves, an exponential horn was placed at the end of the measuring duct. This horn appeared acoustically to the fans and duct as an extending duct of infinite length.<sup>1\*</sup> It was decided that the horn could be constructed most conveniently with a square cross-section and using  $\frac{1}{4}$ -inch plywood. The square exponential section used in the horn made it necessary to insert a two-foot, steel circular-to-square cross-section adapter between the measuring duct and the horn. The adapter was designed with constant cross-section area.

c. Damping - In order to reduce induced vibrations in the duct, the outside of the entire system was coated with about  $\frac{3}{16}$  inch of Komul, a standard Navy preservative, which has a tar-like consistency and color. It was readily observable that the application of the Komul damped the system considerably.

---

\* Appendix - page A-29



interlocking parts were placed between the fans and the  
 1100-Tool mounting gear. This arrangement was  
 were inserted in the duct about 4 feet from the fan in  
 order to reduce the turbulence of air flow. A secondary  
 connection and nitrogen opening were placed in the  
 measuring duct as shown in Fig. 1.

b. Exponential Horn - In order to prevent

wave reflections and resulting standing waves, an exponen-  
 tial horn was placed at the end of the measuring duct.  
 This horn appeared acoustically to the fans and duct  
 as an extending duct of infinite length. It was designed  
 first the horn could be constructed more conveniently with  
 a square cross-section and using  $\frac{1}{4}$ -inch plywood. The  
 square exponential section used in the horn made it neces-  
 sary to insert a two-foot, steel diameter-to-square cross-  
 section adapter between the measuring duct and the horn.  
 The adapter was designed with constant cross-sectional area.

c. Insulation - In order to reduce induced

vibrations in the duct, the outside of the entire system  
 was coated with about  $\frac{1}{2}$  inch of foam, a standard heavy  
 preservative, which has a low thermal conductivity and color.  
 It was readily observable that the application of the  
 foam dampened the system considerably.

## 2. Back Pressure

In order to create back pressure in the measuring ducts, a fine mesh screen, with four layers of cloth attached thereto, was secured firmly over the horn mouth. This arrangement was used during part of the tests, only.

## 3. Fans and Speed Control

Speed control was obtained in both fan tests by placing a variable resistance in the armature circuit of the direct-current motor supplied with the fan. A starting box was placed across the 110-volt d-c supply line.

## 4. Measuring System

The measurements in these tests included measurements of speed, power, back pressure, and sound-pressure level. The speed of the fans was measured by means of a stroboscope. The power input was measured only in the test of the  $A\frac{1}{2}$  fan, which has a series wound motor. The mechanical power was calculated from measurements of terminal voltage and motor current, using field and armature resistance determined from a blocked rotor test. Simpson meters were used for the electrical measurements. Back pressure was measured by means of a draft gauge manometer connected by a fitting in the top of the duct.

### 3. Speed Control

In order to obtain back pressure in the  
 measuring device, a line with a valve, with four liters  
 of liquid nitrogen changed, was placed directly over the  
 heat source. This arrangement was used during part of  
 the tests, only.

### 4. Heating System

Speed control was obtained in both the  
 tests by placing a variable resistor in the circuit  
 circuit of the direct-current source supplied with the  
 fan. A starting box was placed across the 110-volt d-c  
 supply line.

### 5. Measuring System

The measurements in these tests included  
 measurements of speed, power, back pressure, and sound-  
 pressure level. The sound of the fan was measured by  
 means of a stroboscope. The power input was measured  
 only in the test of the  $\frac{1}{2}$  fan, which has a series  
 wound motor. The mechanical power was calculated from  
 measurements of terminal voltage and motor current.  
 static field and current relationships. The  
 plotted static field. The power input was measured by  
 electrical measurements. Back pressure was measured by  
 means of a differential manometer connected by a fitting  
 in the top of the duct.

The sound measuring system was designed to obtain, as accurately and as simply as possible a measurement of the absolute sound-pressure level referred to  $0.0002 \text{ dyne/cm}^2$ . Overall as well as narrow-band measurements were desired.

Basically, the system consisted of an Altec-Lansing, Model 21-B condenser microphone; Altec-Lansing 40-db line amplifier; a Ballantine Laboratories, 0.001 - 100-volt vacuum-tube voltmeter; and a Telefon one-third octave filter. Each component was calibrated, and from this calibration direct readings of absolute sound-pressure level were determined.\*

The 21-B microphone was chosen because of its small physical dimensions. Being small it was not expected to disturb seriously the sound field in the range of frequencies (100 - 10,000 cps) considered for the test. An effective windscreen with reasonably small dimensions could be fitted around it. Besides having a desirable size and shape, the frequency response was reasonably flat over most of the range considered.\*\*

---

\* Appendix - page A-3

\*\* Appendix - page A-4

The sound measuring system was designed to

obtain, as accurately and as simply as possible a

measurement of the acoustic wave-pressure level (referring to 0.002 dyn/cm<sup>2</sup>). Details as well as circuit diagrams and drawings were designed.

Basically, the system consisted of an electric

coupling (Model 24-B condenser microphone) - amplifier (Model 24-B line amplifier) - a balanced transformer (0.001 - 100-volt vacuum-tube voltmeter) and a relay (see Fig. 1) - relay circuit. Each component was calibrated, and from

this calibration direct readings of acoustic wave-pressure level were obtained.

The 51-8 microphone was chosen because of its

small physical dimensions. Being small it was not expected

to disturb seriously the sound field in the range of

frequencies (100 - 10,000 cps) considered for the test.

An extensive investigation into frequency scale limitations could be fitted around it. Besides having a resonance

line and shape, the frequency response was reasonably

flat over most of the range considered.

\* Appendix - page 4-3  
\*\* Appendix - page 4-4



PLATE I

FAN A $\frac{1}{2}$  AND DUCT SYSTEM

SHOWING BACK PRESSURE SCREEN AND A $\frac{1}{2}$  EXPANSION SECTION

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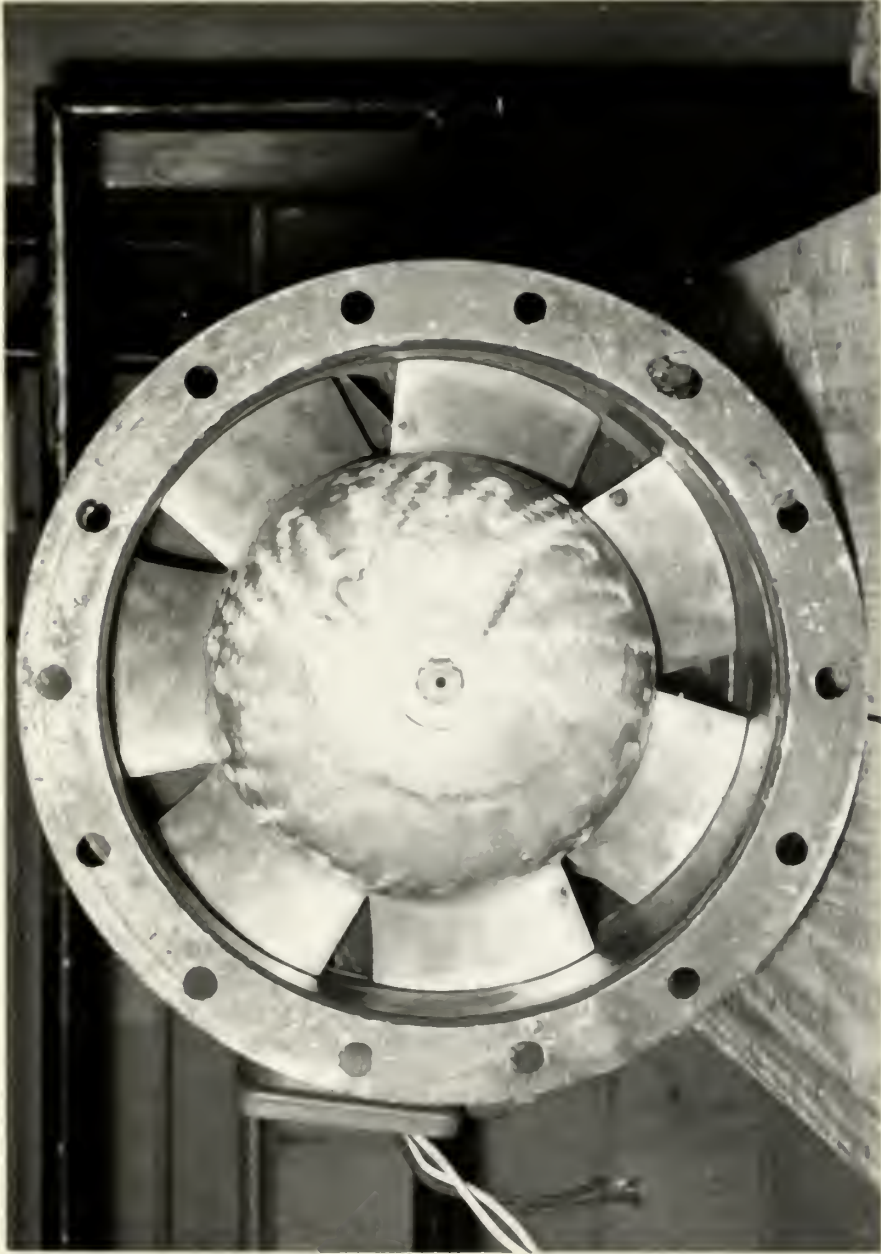


PLATE II

PAN A $\frac{1}{2}$  INTAKE END



1000 of 1000000000

1000000000

1000000000

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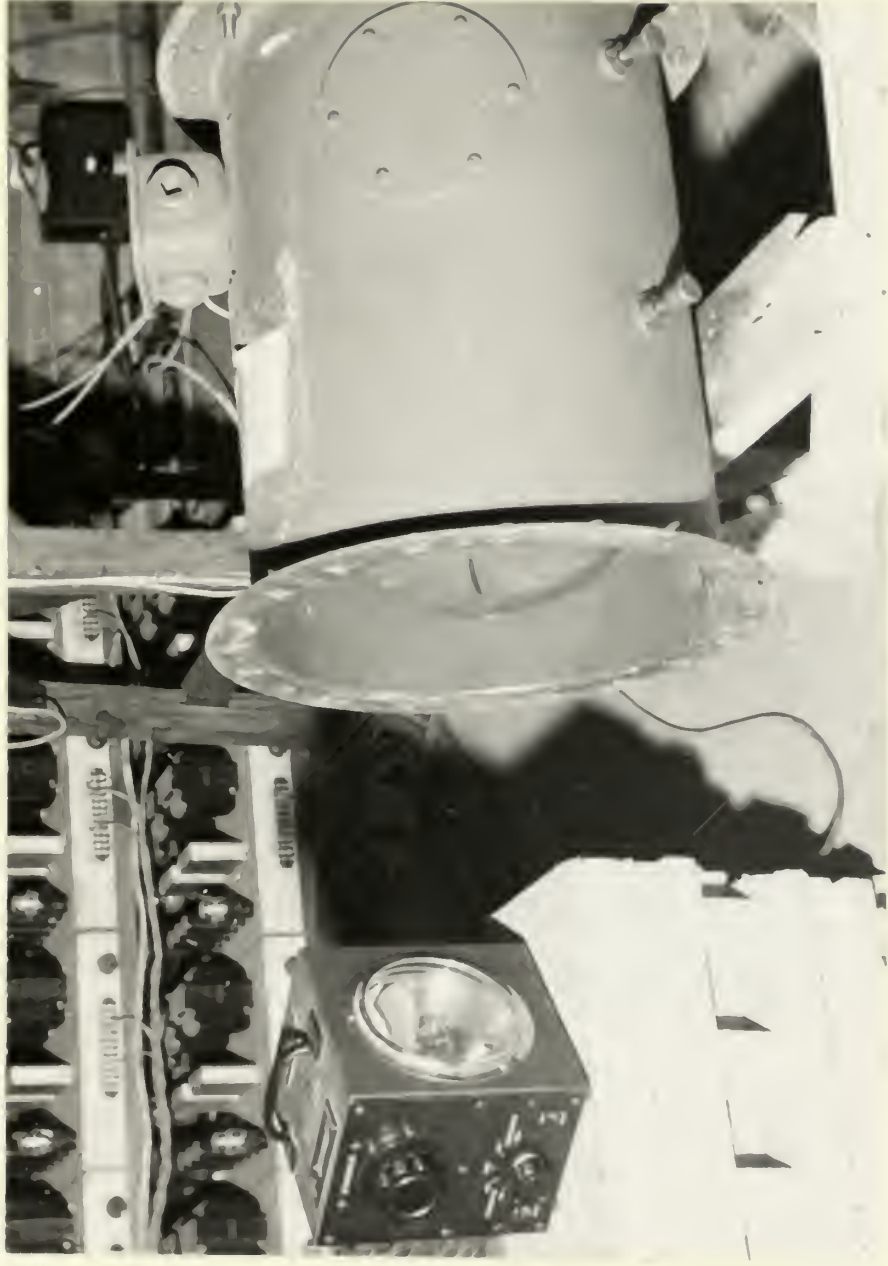


PLATE III

FAN A1 $\frac{1}{2}$  AND STROBOSCOPE

ЛВИ УГЛ<sup>8</sup> УИД СЛНОВСОСОВС

ТТТ СТАЛТ

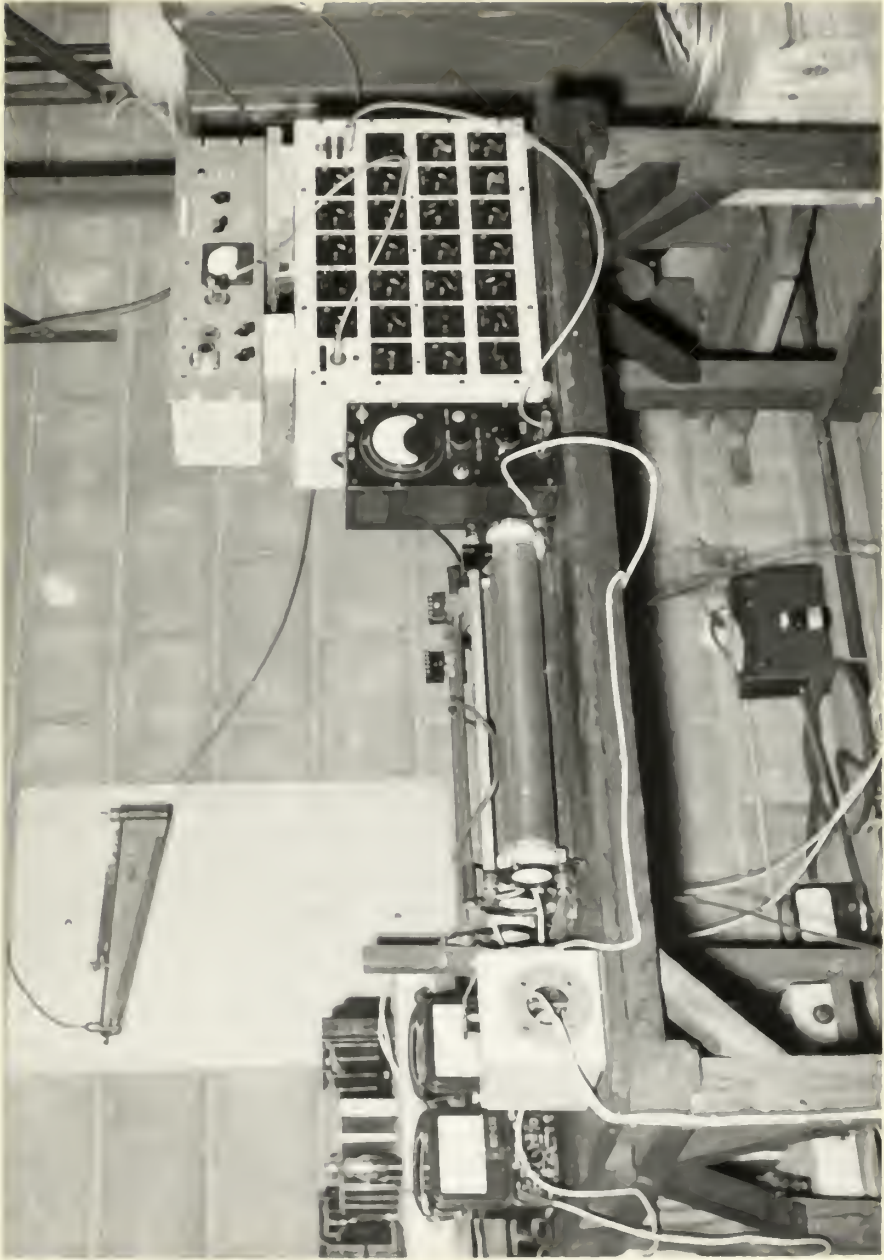


PLATE IV  
FAN SPEED CONTROL AND  
MEASURING INSTRUMENTS





PLATE V

INSIDE OF DUCT SHOWING MICROPHONE  
MICROPHONE WINDSCREEN AND STRAIGHTENING VANES

PLATE I

MICROPHONIC WINDSHEETS AND SPRAYING TANKS  
INSTEAD OF CUTS SHOWING MICROPHONIC

The Altec-Lansing line amplifier was chosen for its stability as compared with the battery-powered amplifiers used in sound-level meters. Its response is relatively flat over the 100 - 10,000 cps band that was considered. This amplifier also contains the power supply for the vacuum-tube at the base of the Altec, 21-B microphone.

In order to determine the frequency spectra of the fans, the one-third octave filter was inserted between the amplifier and the voltmeter used for the SPL indication. The input impedance adjustment of the filter was set to 10,000 ohms to match the output of the line amplifier.

The filter was checked with an oscillator to ascertain the band shapes, the attenuation to be expected, and the bounding and center frequencies of each band.\*

The Telefon filter has sharply defined pass bands and a flat response between 100 and 10,000 cps. The deviation is small and was neglected for the bands in which it applied.

---

\* Appendix - page A-5



The first-order line amplifier was chosen for the study as compared with the second-order amplifier used in some other papers. It is assumed that the amplifier has a gain of 10,000 and that it is relatively flat over the 100 - 10,000 cps band that was considered. This amplifier also contains the delay which for the present work is the same as the delay of the amplifier.

In order to determine the frequency spectrum of the filter, the gain-bandwidth filter was inserted between the amplifier and the vibrator used for the SVP excitation. The input impedance adjustment of the filter was set to 10,000 ohms to match the output of the line amplifier.

The filter was checked with an oscilloscope to determine the band shape. The attenuation for the frequencies above and below the passband was checked, and the results are shown in Figure 1.

The filter filter has sharp roll-off characteristics and a flat response between 100 and 10,000 cps. The deviation is small and was neglected for the work in which it is used.

The "range of accuracy" of the measurements, mentioned above, was controlled primarily by the noise conditions around the Acoustics Laboratory. The accuracy of the equipment and calibration was better than the estimated accuracy of  $\pm 1$  db which resulted from reading fluctuations. There were large fluctuations in overall SPL and in spectrum measurements below about 1000 cps, but the measurements in the upper range of the spectrum were quite steady. Since the sound field conditions set a limit of precision of about  $\pm 1$  db, the small deviations from flat response in the filter and the microphone should not cause the limits in accuracy to be greater than  $\pm 2$  db.

#### B. Test Procedure

After the first fan, duct system, and measuring equipment were readied for the experiment, data were recorded to insure the adequacy of the horn in preventing standing waves in the measuring duct. Neglecting the horn-wall losses, the sound power passing through the duct is constant. The decrease in intensity level, as the microphone was moved out from the horn throat toward the mouth, could be predicted from theory to vary linearly with the axial distance from the horn throat.\*

-----

\* Appendix - page 31

The range of error, at the measurement  
 position above, was calculated by the ratio  
 condition around the inverse laboratory. The accuracy  
 of the equipment and calibration was better than the  
 estimated accuracy of  $\pm 1$  or which resulted from testing  
 fluctuations. There were large fluctuations in overall  
 and in specific measurements below about 1000 cps,  
 but the measurements in the upper range of the spectrum  
 were quite steady. Above the sound field conditions  
 and a limit of variation of about  $\pm 1$  dB was found.  
 deviations from that between in the filter and the  
 microphone should not cause the limits in accuracy to  
 be greater than  $\pm 2$  dB.

### 3. Sound Spectra

After the first run, four series, the measuring  
 equipment was tested for the accuracy, this was  
 recorded to insure the accuracy of the data in presenting  
 existing error in the material. The following are  
 non-wall losses, the sound power passing through the  
 duct in constant. The decrease in intensity is  
 as the microphone was moved out from the duct  
 toward the source. could be predicted from theory to vary  
 directly with the axial distance from the source.

This theoretical variation is plotted as the solid line in Fig. 10, page A-32. Sound-pressure levels were recorded at two axial positions in the adapter and four positions in the horn. Readings were also taken at off-center positions and were found to agree with values along the horn center line. The variation of levels at the various axial positions from the level at the horn throat were also plotted as a function of axial horn position for six fan-operating speeds. Due to fluctuations in the sound-pressure level readings, these values are considered accurate to  $\pm 1.5$  db.

It can be seen from Fig. 10, page A-32, that this  $\pm 1.5$  db region from the theoretical curve includes the majority (80 percent) of the measured points. It was felt that the experiment could be continued with the assurance that the exponential horn was adequately preventing standing waves.

Sound-pressure levels were observed in the measuring section and compared with those taken in the adapter. In this comparison, all readings were made with the microphone on the center line of the duct. At any particular speed, levels at the various axial positions

This frequency spectrum is shown in Fig. 1. The spectrum was measured at two axial positions in the upper and lower portions of the bore. The results were also taken at 45-degree positions and were found to agree with values along the bore center line. The variation of levels at the various axial positions from the level at the bore center was also plotted as a function of axial bore position for six different operating speeds. The so-called "bore" in the sound pressure level readings, these values are considered accurate to  $\pm 1.5$  dB.

It can be seen from Fig. 1, page 2-10,

that the 1.5 dB variation from the theoretical curve indicates the accuracy of the measurements. It was felt that the agreement could be compared with the accuracy of the experimental data, and therefore the theoretical curve was also plotted.

Sound pressure levels were measured in the

measuring section and compared with those in the adjacent section. In this comparison, it was found that the difference in the pressure level of the two sections was negligible.

agreed to within 2 db. This was considered sufficiently close to the accuracy of any particular reading to justify the assumption that the axial position of the microphone in the duct did not affect the sound-pressure level measurement.

The next test was a determination of the effect of varying the radial position of the microphone in the duct-measuring section. For the  $A\frac{1}{2}$  fan, readings were taken at 3, 6, and 8-inch distances from the duct center for 1000 and 2000 RPM. At the rated speed, levels were recorded at the duct center and at eight other radial positions, spaced 1 inch apart. The frequency spectrum check showed that, at rated speed, no variation in readings occurred below 500 cps and above 4000 cps as the microphone was moved radially outward from the duct center. However, between these frequencies, the sound-pressure level increased as the distance from the duct center was increased. The maximum difference between sound-pressure levels at the duct center and at position eight, 8 inches from the duct center, was 12 db - this difference being noted at about 800 cps. (Fig. 8 - page A-8). At 1000 and 2000 RPM, maximum difference was at a lower frequency. It is believed that these variations in levels were due to vibrations induced in the duct walls. No specific cause could be determined since a consistent



relationship linking the frequency of maximum sound level variation to the duct dimensions could not be found. It was therefore decided to make all frequency spectrum readings at the duct center.

Overall sound-pressure levels were taken at the duct center and at three radial positions off the center. An average overall sound-pressure level was then obtained from the average of the four measured sound pressures.

The final preliminary check was a determination of the contribution of wind noise to the SPL throughout the frequency spectrum. The test was made for the  $A\frac{1}{2}$  fan at its rated speed. SPL's were measured with and without the microphone windscreen. The levels obtained with the screen were consistently below those measured without the screen, the larger differences occurring at high frequencies. (Fig. 9 - page A-10) This effect was expected, and it was decided to use the microphone windscreen for all further experimentation.

After these preliminary tests of the exponential horn, the effect of microphone radial and axial positions, and the effect of the windscreen, tests were commenced



rejection of the hypothesis of a simple  
level of organization for the data obtained could not be  
found. It was therefore decided to run all frequency  
spectra at the same time.

Typical sound-pressure level vs. time  
at the four points and at three initial positions of  
the ear. An average overall sound-pressure level  
was then obtained from the average of the four  
sound-pressure levels.

The final preliminary work was a determination  
of the sensitivity of the ear to the 1000 cps  
frequency spectrum. The test was made for the  
ear at the four points. The ear was covered with  
viscous tape throughout the experiment. The results obtained  
with the ear were compared with those obtained  
without the ear. The larger differences occurring  
at high frequencies (1000 - 2000 cps) are  
shown in Figure 1, and it was decided to use the  
sensitivity obtained for all further experiments.

After these preliminary tests of the experimental  
method, the effect of frequency on the ear was  
studied and the effect of the frequency on the ear was

to determine the sound-power output of the ventilating fan. SPL's were recorded for the  $A\frac{1}{2}$  fan at 14 speeds ranging from 800 to 3450 RPM. For the  $A1\frac{1}{2}$  fan, data were recorded at the same speeds as for the  $A\frac{1}{2}$ ; and, in addition, readings were made at 3800, 4200, and 4600 RPM. Levels were recorded with no back pressure; and the runs were repeated with the back pressure wind-screen in place at the horn mouth. SPL's were measured for both fans at each speed over a frequency range of 100 - 10,000 cps, using the one-third octave band analyzer for frequency selection. Overall levels were also recorded at each speed at four radial positions, and the average of these was taken as the overall SPL.

At the conclusion of these tests, the  $A\frac{1}{2}$  fan was operated in the reversed position. Using the octave-band analyzer, SPL'S were measured in the duct with the fan running at rated speed.

In addition, readings were taken at 5000, 10000, and 15000 rpm. Levels were recorded with the same procedure and the two were compared with the same procedure. The two were compared with the same procedure. The two were compared with the same procedure.

The two were compared with the same procedure. The two were compared with the same procedure. The two were compared with the same procedure.

The two were compared with the same procedure. The two were compared with the same procedure. The two were compared with the same procedure.

The two were compared with the same procedure. The two were compared with the same procedure. The two were compared with the same procedure.

The two were compared with the same procedure. The two were compared with the same procedure. The two were compared with the same procedure.

### III. POWER LEVEL

Power levels were used in the presentation of data obtained from these tests because in an acoustical analysis of ventilating duct systems, the basic quantity needed is acoustic power. Sound-pressure level in a duct, having no losses through its walls, decreases with increasing cross-sectional area; however, again neglecting losses, power level is independent of cross-sectional area.

Now consider a system in which wall losses are taken into account. If the sound power supplied to a duct system by a ventilating fan can be measured or computed, it is possible

- 1) To predict the sound-pressure levels in a room supplied by the ventilating system, if the duct wall losses and the propagation constants of the given system are known, and
- 2) To calculate the number of additional power absorption units in the duct system necessary to achieve sound-pressure levels below a specified value in the room.

APPENDIX I

These levels were used in the determination of data obtained from these tests because it is essential that analysis of ventilating duct systems, the design method as described here, should be based on a flow, rather than on pressure through the duct, and because with increasing duct resistance, the flow, rather than the pressure, is the important factor in determining the system's performance.

The constant  $k$  system in which will be used in the test series. If the constant  $k$  system is used as a duct system in a ventilating fan can be compared as compared, it is possible.

1) To provide the same pressure levels in a room supplied by the ventilating system. If the fan will operate and the pressure in the duct system is known, the

2) To calculate the number of additional fans required with in the duct system necessary to provide the same pressure level in the room.

Power level is defined by the following formula:-

$$PL = 10 \log_{10} \frac{W}{0.9 \times 10^{-13}}$$

W = Power in watts

The SPL in a duct neglecting transverse resonances is related to the power level by the following equation:-

$$SPL^* = PL - 10 \log_{10} A + 29.5 + \log_{10} \left( \frac{293}{T} \times \frac{P}{760} \right) \text{ db}$$

A = Duct cross-sectional area in  $\text{cm}^2$

T = Absolute temperature  $\text{K}^\circ$

P = Pressure, millimeters of mercury.

In this investigation pressure and temperature conditions were sufficiently close to standard to be able to neglect the last term in the relationship above.

Power level is defined by the following

Equation:

$$P = 10 \log_{10} \frac{W}{0.001 \times 10^{-12}}$$

W = Power in watts

The SWR is a point electrical parameter

measured in relation to the power level by the following

Equation:

$$SWR = \frac{1 + \sqrt{\frac{P_{ref}}{P_{max}}}}{1 - \sqrt{\frac{P_{ref}}{P_{max}}}}$$

A = Total cross-sectional

area in cm<sup>2</sup>

T = Absolute temperature in

degrees Celsius

velocity

In this investigation pressure and temperature

conditions were maintained close to standard so as not

to affect the test results in any appreciable way.

It is noted that the test results are in good agreement

with the theoretical values.

The test results are shown in the following graphs.

-----

\* Appendix - Test Data

#### IV. RESULTS

##### Frequency Spectra

The investigation of noise spectra of the fans tested produced apparently good results. The previously used test procedure for Navy ventilating fans did not include a spectrum check, so there was no direct method available for checking the quality of the data. Since the noise producing mechanism of the axial-flow fan is similar to that of an airplane propeller, it was felt that the noise resulting from the two sources should have similar characteristics. Reliable data are available concerning the behavior of an aircraft propeller as a function of speed and shaft power<sup>2-3</sup>. The airplane propeller data agreed generally with the spectra obtained above 100 cps from the ventilating fans.

The detailed investigation of spectra obtained from fan A $\frac{1}{2}$  at various speeds revealed distinct peaks at the fundamental and fourth harmonic of the blade frequency. (Fig. 2.) The vertical lines connect corresponding points on the spectrum curves and the harmonic curves. It can also be seen that the second harmonic had a negligible effect on the spectrum.



IV. RESULTS

Frequency Spectra

The investigation of noise spectra of the  
 type tested produced apparently good results. The pro-  
 cedure used test procedure for many existing tests  
 did not include a spectrum check, so there was no direct  
 means available for checking the quality of the data.  
 Since the noise producing mechanism of the test-flow fan  
 is similar to that of an electrical generator, it was felt  
 that the noise resulting from the two sources should have  
 similar characteristics. Relations data are available  
 concerning the behavior of an electrical generator as a  
 function of speed and shaft power. The electrical power  
 factor data varied generally with the speed obtained  
 above 100 rpm from the existing data.

The detailed investigation of spectra obtained  
 from the  $\frac{1}{2}$  at various speeds revealed distinct peaks  
 at the fundamental and fourth harmonics of the blade  
 frequency. (Fig. 2.) The vertical lines connect cor-  
 responding points on the spectrum curves and the harmonic  
 curves. It can also be seen that the second harmonic had  
 a significant effect on the spectrum.

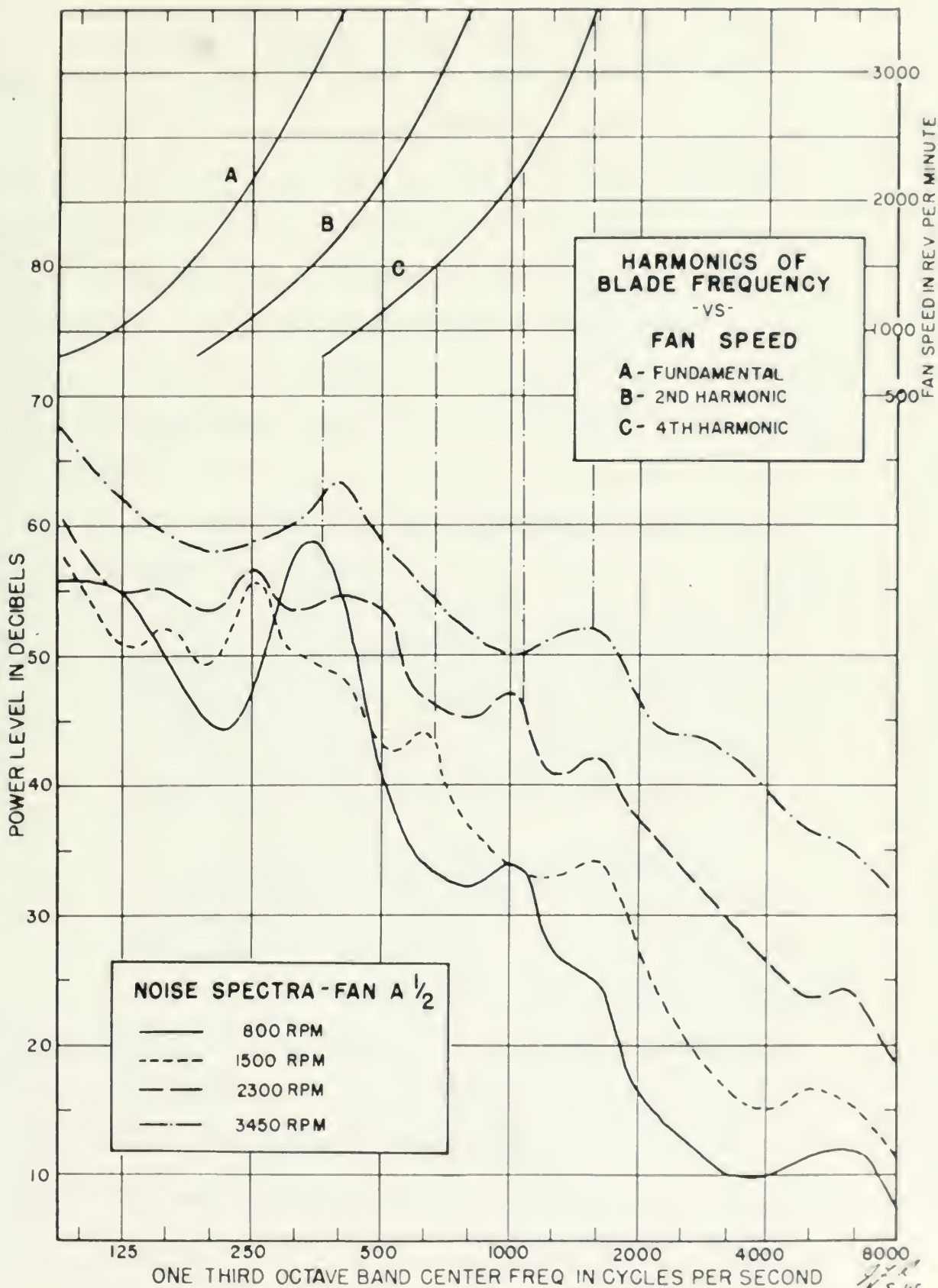


FIGURE 2

*R. S. W.*  
5/9/52



This is not in strict agreement with a theory developed by Professor O. K. Mawardi<sup>4</sup> which has been applied to axial-flow compressors for pressure variation near the blades. This theory, based on the assumption of incompressible flow, predicts a wave form at the blade tip containing large second and fourth harmonic components. No attempt will be made to explain the absence of the second harmonic, but the following deviations from the conditions upon which the theory is based should be noted:-

- a. Measurements were made relatively far from the blades.
- b. The blade section is not the standard Joukowsky air foil section used by Dr. Mawardi in his development of the theory for axial-flow compressors.
- c. The flow is probably not perfectly incompressible as assumed.

The latter deviation probably has little effect in the case of the  $A\frac{1}{2}$  fan, since a pressure check near the blades yielded a wave form which has predominant second and fourth harmonic components. On the other hand, compressibility and the high level of the turbulent noise are probably the reasons for the complete absence

This is not in strict agreement with a theory developed by Professor O. E. Sawada<sup>1</sup> which has been applied to axial-flow compressors for pressure variation near the blades. This theory, based on the assumption of incompressible flow, predicts a wave form at the blade tip containing large second and fourth harmonic components. An attempt will be made to explain the absence of the second harmonic, but the following deviations from the conditions upon which the theory is based should be noted:-

- a. Measurements were made relatively far from the blades.
- b. The blade section is not the standard Joukowski air foil section used by O. E. Sawada in his development of the theory for axial-flow compressors.
- c. The flow is probably not perfectly incompressible as assumed.

The latter deviation probably has little effect in the case of the  $\frac{1}{2}$  in. axial compressor since near the blades yielded a wave form which has pronounced second and fourth harmonic components. On the other hand, compressibility and the high level of the velocity noise are probably the reasons for the complete absence

of identifiable harmonic peaks in the spectra of the  $A\frac{1}{2}$  fan. (Fig. 3).

No analysis is known to the authors which applies to compressible flow around air foils. Therefore, the comparison with the propeller spectrum for agreement of trend is again used to estimate the quality of the test data. Although the octave spectrum of a propeller measured inside an airplane drops off much more rapidly than does that of a fan, as would be expected, the general trend is the same. This degree of agreement, coupled with the close agreement in trends for the two fans tested, indicates that the data presented probably give a true indication of the noise spectrum of the source.

Spectrum measurements were made for both fans with and without back pressure. The agreement in Fig. 4, indicated that the small increase in blade loading which resulted, produced an average reduction in spectrum level of about 2.5 db. It should be noted that the back pressures obtained were relatively small. For the  $A\frac{1}{2}$ , the maximum pressure obtained was 0.325 inches of water gauge, and for the  $A\frac{1}{2}$  the maximum pressure was 0.70 inches of water gauge.

of identical acoustic beams in the spectra of the  $\frac{1}{2}$  ton. (Fig. 5).

It appears to follow in the authors' opinion that the comparison with the acoustic spectra for agreement of level is again used to estimate the quality of the test data. Although the degree of agreement of the spectra measured inside an airplane drops off somewhat more rapidly than does that of a ton, as would be expected, the general trend is the same. This degree of agreement, coupled with the close agreement in trends for the two tones tested, indicates that the data presented probably give a fair indication of the noise spectrum of the engine.

Positive measurements were made for both tones with and without head pressure. The agreement in Fig. 4, indicated that the small increase in blade loading when installed, produced an average reduction in spectral level of about 2.5 db. It should be noted that the head pressures obtained were relatively small. For the  $\frac{1}{2}$  ton, the maximum pressure obtained was 0.005 inches of water gauge, and for the  $\frac{1}{4}$  ton maximum pressure was 0.002 inches of water gauge.

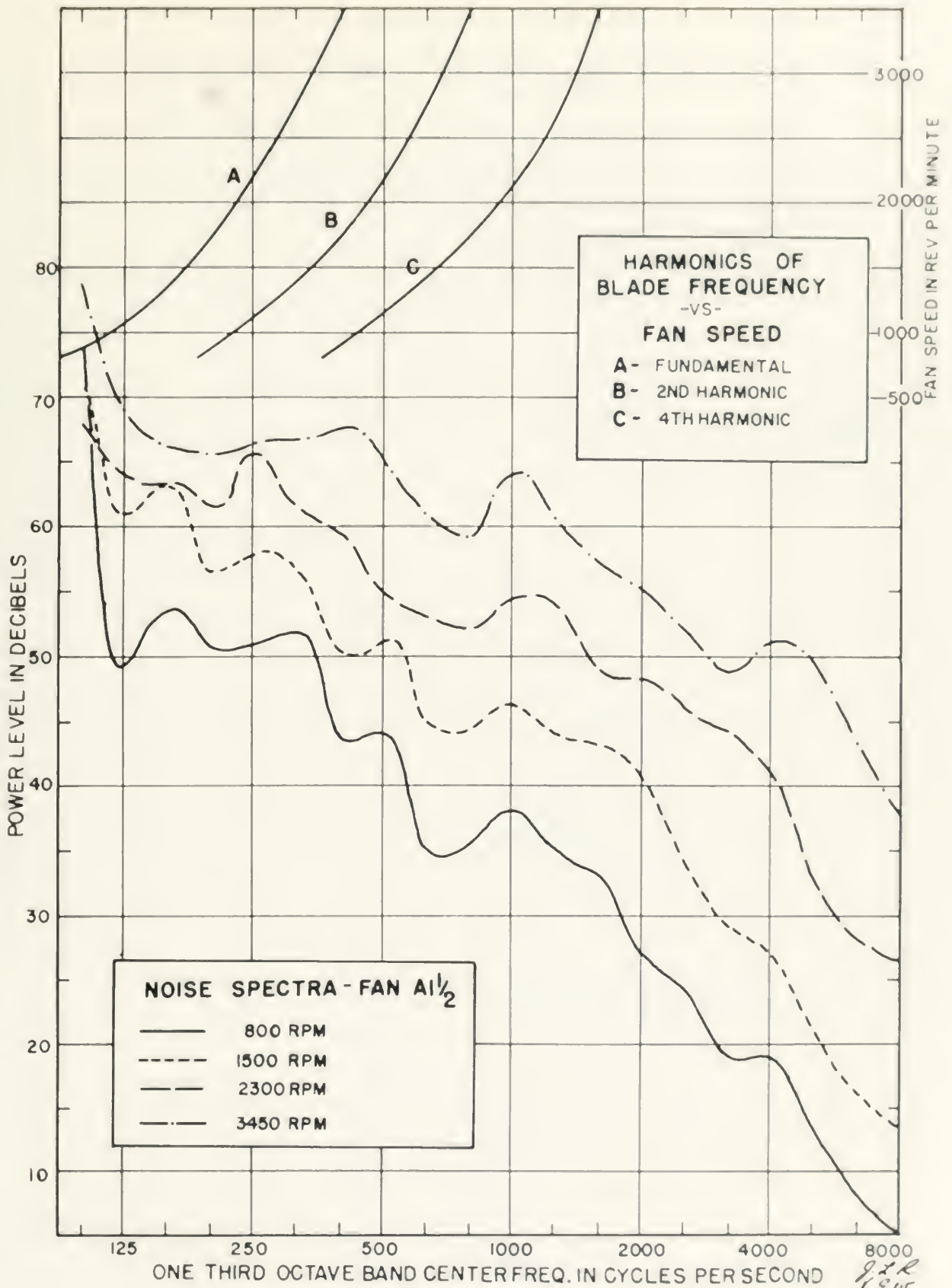


FIGURE 3

*J.R.  
L.E.W.  
5/9/52*





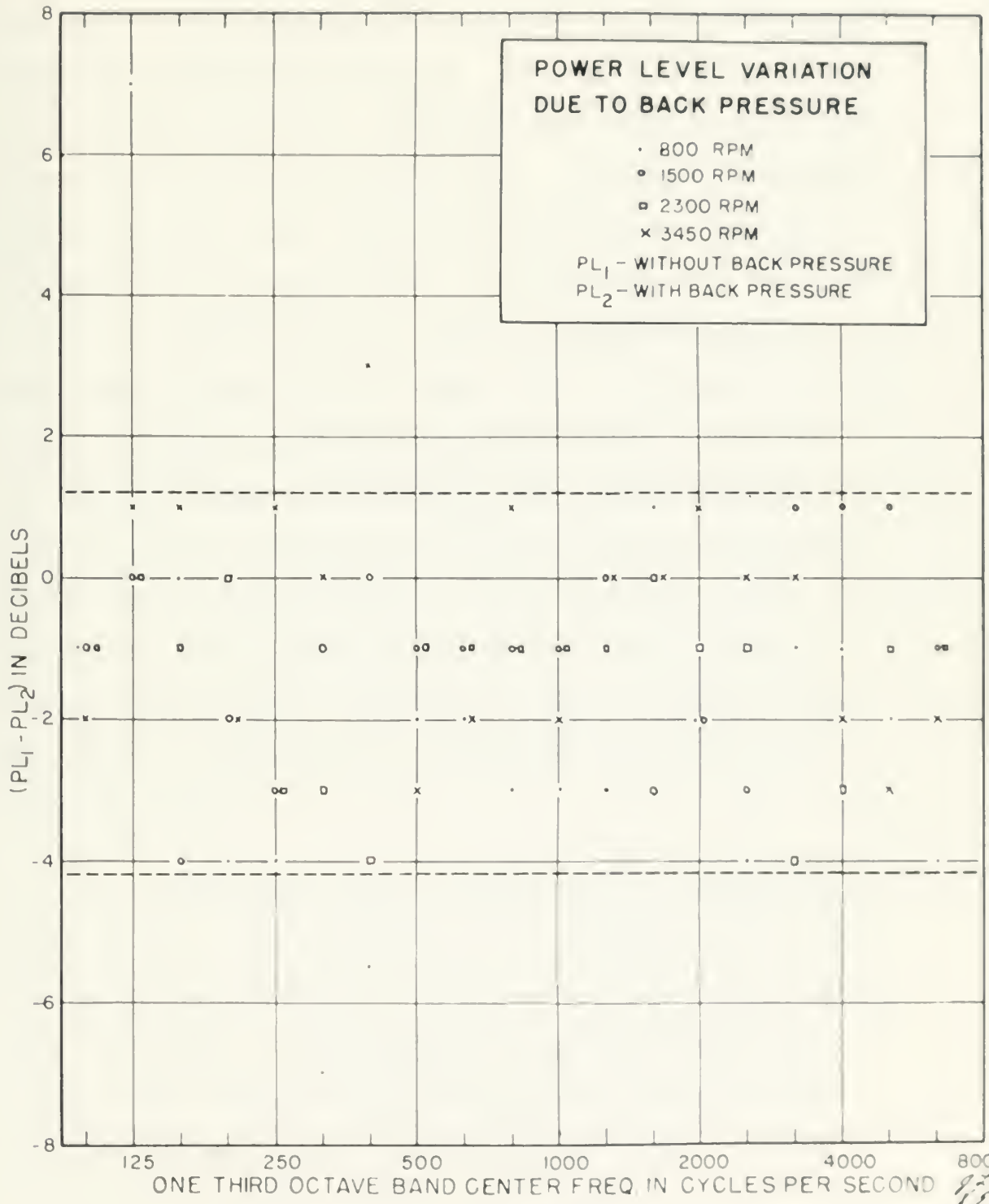


FIGURE 4

9-22  
L.E.W.  
5/1/52



### Overall Power Level

The average overall sound-power levels in decibels were calculated and plotted for the zero back pressure condition in Fig. 5. The small back pressures used caused very small reduction in overall power level from the zero back pressure case. At speeds above 2000 RPM, the plots give smooth curves of increasing power level with increasing speed. It is noted that the power level at 3200 RPM for the  $A\frac{1}{2}$  fan is 6.5 db higher than the smoothed curve. This value was caused primarily by an unusually high sound-pressure level in the 80 to 125-cps region. It is felt that this high level was a result of duct and associated system vibrations rather than the fan output. Large floor and duct vibrations were noted at this speed. Since overall power levels at all other speeds form a smooth curve, the value at 3200 RPM was neglected in drawing the smoothed curve.

The major cause of noise in the ventilating fans is the beating of the air by the fan blades and the disturbing influence of the fan straightening vanes and fan casing. In the  $A\frac{1}{2}$  fan, high sound-pressure levels were noted at high frequencies after the fan had been operating for some length of time. It is

Overall Power Level

The average overall sound-power levels in decibels were calculated and plotted for the two peak pressure conditions in Fig. 2. The peak pressure level caused very small reduction in overall power level from the same peak pressure case. At speeds above 2000 RPM, the plots give smooth curves of increasing power level with increasing speed. It is noted that the power level at 2000 RPM for the  $A\frac{1}{2}$  fan is 2.9 dB higher than the smoothed curve. This value was caused relatively by an unusually high sound-pressure level in the 50 to 100-cps region. It is felt that this high level was a result of dust and associated system vibrations rather than the fan output. Large filter and dust absorbers were noted at this speed. Since overall power levels at all other speeds form a smooth curve, the value at 2000 RPM was neglected in drawing the smoothed curve.

The major cause of noise in the ventilating fans is the beating of the air by the fan blades and the disturbing influence of the fan revolving vanes and fan casing. In the  $A\frac{1}{2}$  fan, high sound-pressure levels were noted at high frequencies after the fan had been operating for some length of time. It is

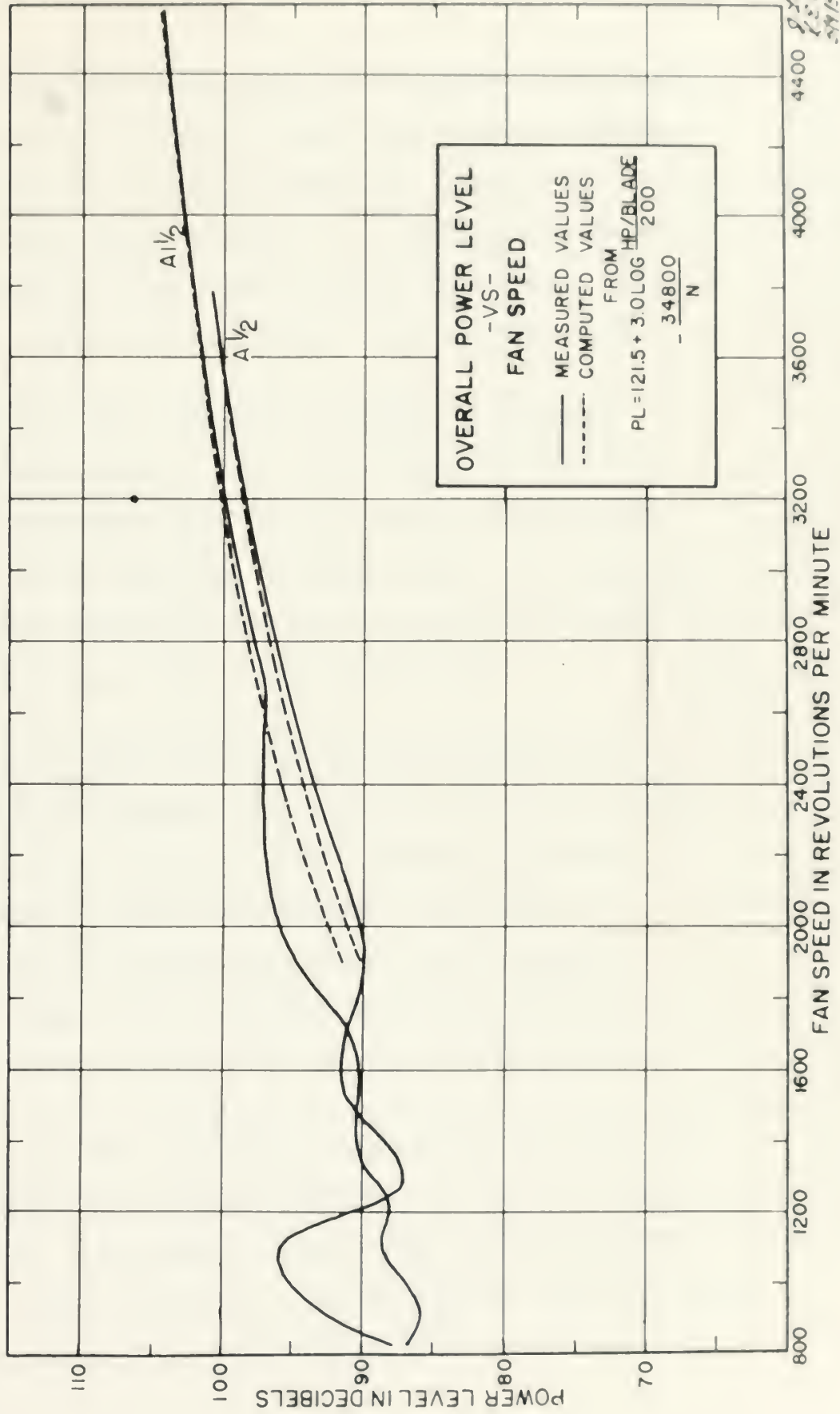


FIGURE 5



believed that these high levels were caused by fan motor noise. This high frequency noise was clearly audible without earphones, and with earphones could be heard in frequency bands above 5000 cps. In testing the  $A\frac{1}{2}$  fan, large differences were noted between the overall level at the duct center and the level near the duct wall.

It is believed that vibrations, caused by improper fan motor construction, were transmitted through the duct walls causing higher sound-pressure levels near the wall. In the  $A1\frac{1}{2}$  fan, no motor noise was observed; and a maximum difference of 3 db was observed between levels at the duct center and near the wall.

An empirical formula has been derived for sound levels of airplane propeller noise.<sup>2-3</sup> This formula is based on data measured in the aircraft cabin and is a function of engine horsepower, propeller tip velocity, and the minimum propeller tip clearance. The sound-power levels computed by this formula correspond to that measured in the 75 - 150-cps octave.

A similar empirical formula has been derived by the authors for ventilating fans. In the aircraft measurements, the highest sound level was consistently in the 75 - 150-cps octave. In the  $A\frac{1}{2}$  and  $A1\frac{1}{2}$  ventilating fans, high levels were measured in this region; but at



believed that these high levels were caused by fan noise. This high frequency noise was clearly audible without earmuffs, and with earmuffs could be heard in frequency bands above 2000 cps. In testing the  $\frac{1}{2}$  fan, large differences were noted between the overall level at the duct center and the level near the duct wall.

It is believed that attenuation, caused by frequency fan noise deterioration, were transmitted through the duct walls existing higher sound-pressure levels near the wall. In the  $\frac{1}{2}$  fan, no motor noise was observed and a maximum difference of 3 db was observed between levels at the duct center and near the wall.

An empirical formula has been derived for sound levels of airplane propeller noise. This formula is based on data measured in the aircraft cabin and in a location of engine development, propeller tip velocity, and the minimum propeller tip clearance. The sound-power levels computed by this formula are compared to that measured in the T2 - 130-cps octave.

A similar empirical formula has been derived by the authors for ventilating fans. In the aircraft measurements, the highest sound level was consistently in the T2 - 130-cps octave. In the  $\frac{1}{2}$  and  $\frac{1}{4}$  ventilating fans, high levels were measured in this region, but at

some speeds, higher sound levels were observed at higher frequencies. Thus, it seemed more plausible to base the derived formula for ventilating fans on overall power level rather than the level of any particular octave. The formula below was derived to give sound-power levels in good agreement with the measured values. It was noted from the experimental data that the PL curves for the two fans were parallel above 2600 RPM. A tip speed term, as in the aircraft formula, would give different slopes for fans of different diameters. The desired result was attained by replacing the tip speed term with a function of rotational speed.

$$PL = 121.5 + 3.0 \log_{10} \frac{HP/Blade}{200} - \frac{34800}{n} + 10 \log_{10} \frac{N}{7}$$

Equation 1

- PL = Power Level in Decibels
- HP = Total Fan Horsepower
- n = Fan Speed, RPM
- N = Number of Blades

The total horsepower delivered to the  $A\frac{1}{2}$  fan by its series wound motor was computed at each speed by measuring the fan motor terminal voltage and the armature current. The armature resistance was determined by test to be 1.75 ohms. The horsepower, calculated from these measurements,\* varied closely as the

-----

\* Appendix - Page A-34



square of the fan speed over the speed range tested. (Fig. 11, page A-35) Motor rotational losses were neglected in computing the horsepower developed at each speed. In the  $A\frac{1}{2}$  unit, the horsepower delivered by the compound wound motor to its fan was not measured. The measured horsepower for the  $Al\frac{1}{2}$  fan at rated speed (3450 RPM) was 0.382 HP with no back pressure applied. The motor name plate for the  $Al\frac{1}{2}$  fan indicated a rating of 1.1 HP at rated speed. For the  $A\frac{1}{2}$  fan, the rated horsepower at 3450 RPM was 0.4 HP. It was assumed that the measured horsepower for the  $A\frac{1}{2}$  fan at 3450 RPM with zero back pressure was

$$\frac{0.4}{1.1} \times 0.382 = 0.140 \text{ HP}$$

The horsepower at the other speeds were then calculated by assuming that in the  $A\frac{1}{2}$ , as in the  $Al\frac{1}{2}$ , total fan horsepower varied as the square of the speed. These horsepower were then used in Equation 1 to obtain computed sound-power levels.

Equation 1 is plotted for both fans in Fig. 5. The derived sound power formula gives agreement to within 1 db of the measured values in the speed range above 2600 RPM for both fans.

The variation in octave-band spectrum caused by reversing the fan position, making the measuring duct end the intake end, is shown in the frequency spectrum plot of Fig. 6.

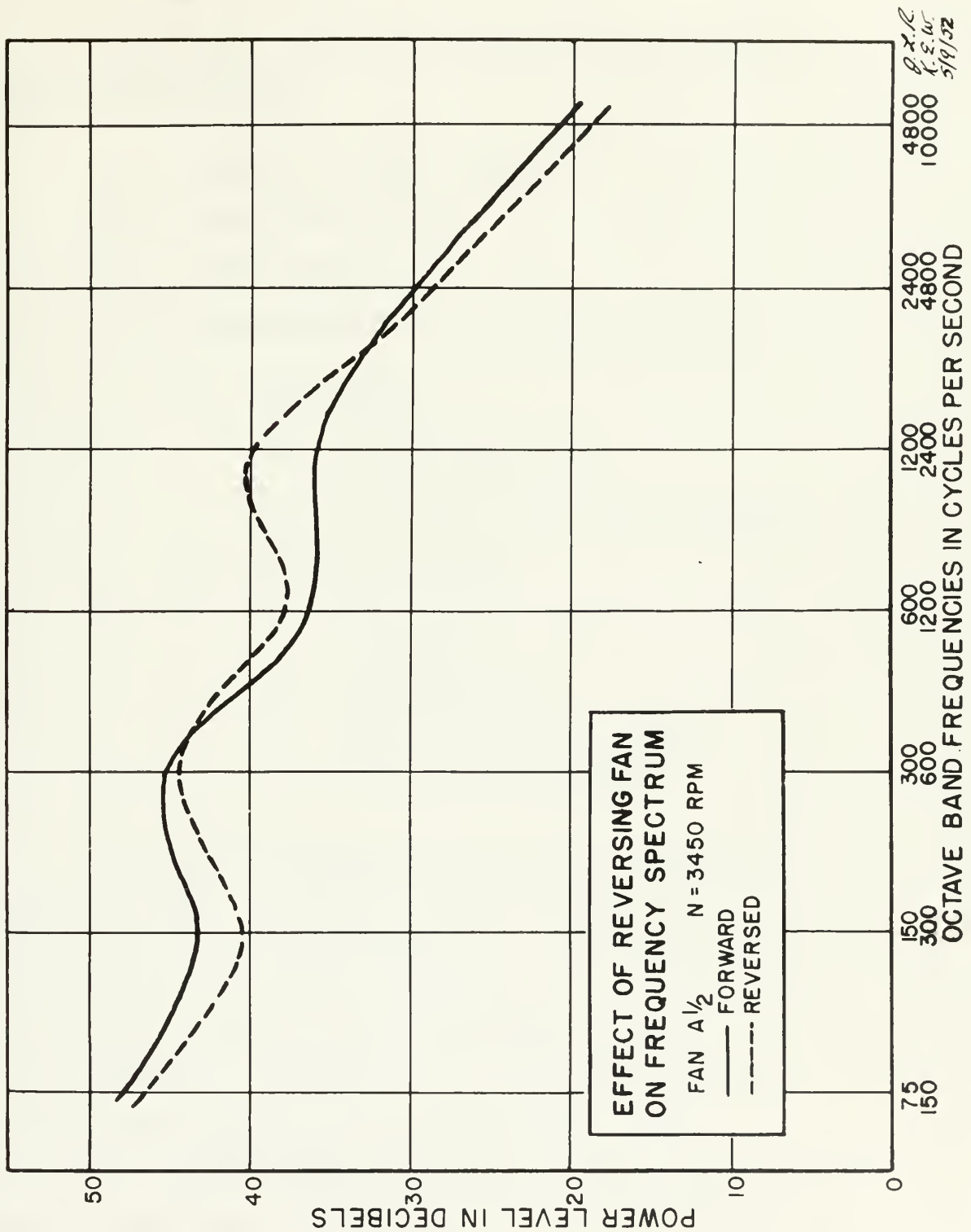
amount of the fan speed with the speed range tested.  
 (Fig. 11, page A-23) Under additional losses were  
 neglected in computing the horsepower developed at  
 each speed. In the  $\frac{1}{2}$  mile, the horsepower delivered  
 by the compound would equal to the fan was not assumed.  
 The assumed horsepower for the  $\frac{1}{2}$  fan at rated speed  
 (1000 rpm) was 0.300 HP with no belt pressure applied.  
 The motor name plate for the  $\frac{1}{2}$  fan indicated a rating  
 of 1.1 HP at rated speed. For the  $\frac{1}{2}$  fan, the rated  
 horsepower is 2450 HP at 0.4 HP. It was assumed that  
 the assumed horsepower for the  $\frac{1}{2}$  fan at 2450 rpm  
 with two inch pressure was

$$2450 \times 0.300 = 0.735 \text{ HP}$$

The horsepower at the other speeds were then calculated  
 by assuming that in the  $\frac{1}{2}$ , as in the  $\frac{1}{2}$ , total fan  
 horsepower varied as the square of the speed. These  
 horsepower were then used in Equation 1 to obtain  
 corrected sound-power levels.

Equation 1 is plotted for each fan in Fig. 2.  
 The actual sound power levels give agreement in values  
 I do not measured values in the speed range shown  
 from the fan test.

The relation in octave-band frequency bands  
 is reversed the fan position using the measured  
 data and the labels are, as shown in the frequency  
 spectrum plot of Fig. 3.



P. X. R.  
K. S. W.  
5/9/52

FIGURE 6



## V. CONCLUSIONS

The points on which a proposed test method should be judged are:-

- A. Quality of data obtained
- B. Usability of data
- C. Repeatability
- D. Characteristics of the test equipment
  - 1. Test Setup
    - a. Reproduceability
    - b. Cost and ease of manufacture
  - 2. Measuring System
    - a. Accuracy
    - b. Availability
    - c. Time required to obtain accurate measurements

In the development of a new test procedure, probably the most difficult point to judge accurately is the quality of the data obtained. On the basis of the consistent trends in spectrum measurements and smooth variations in overall PL as a function of fan speed, the data appear to be satisfactory. This appearance is further reinforced by the good repeatability of datum points which was observed. Variations from one



CONCLUSIONS

The points on which a proposed test method

should be judged are:

- A. Quality of data obtained
- B. Quantity of data
- C. Reproducibility
- D. Characteristics of test equipment

1. Test being

a. Necessarily

b. Cost and ease of maintenance

2. Working system

a. Accuracy

b. Reliability

c. Time required to obtain

desired measurements

In the development of a new test procedure,

probably the most difficult point to judge accurately

is the quality of the data obtained. Of the tests of

the accuracy leads in specific measurements and

each variation in overall as a function of the

speed, the data appear to be satisfactory. This

equipment is further reinforced by the good reproducibility

of data which was observed. Further from the

time of measurement to another seldom exceeded 1 db. A further indication that the data obtained are good is the partial agreement of the spectra of the  $A\frac{1}{2}$  fan with theory applied to axial-flow compressors.

Usability of the data is another point which is difficult to determine when the type data obtained has not been available before.

It is known that this type of data will permit accurate calculations of sound-pressure levels in rooms supplied by a ventilation system if, in addition, the power losses in the duct are known and if available propagation constants in duct liners are used. In other words, only if power levels are known can predictions of levels in rooms be attempted. In addition, this type of measurement permits intercomparison of fans on a logical basis. Also, the spectra obtained could possibly be employed by design engineers to determine the exact origin of the fan noise and thereby assist in redesign to reduce the sound output of axial-flow fans. Through empirical formulas, such as the one presented here, more exacting acceptance standards might be set down. Consideration of only these possibilities leads to the conclusion that this test method yields usable data.

time of measurement is another value recorded  $\pm$  db.  
A further remark is that the data obtained are good  
in the partial agreement of the order of the  $\frac{1}{2}$  law  
with theory applied to relaxation phenomena.

Results of the data in another point which  
is difficult to describe than the type obtained  
has not been analyzed before.

It is shown that this type of data will permit  
a more accurate calculation of bond-pressure levels in some  
examples of a vibration system II, in addition, the  
order forces in the case are known and it is possible to  
calculate constants in that theory etc. In other  
words, only if some levels are known can predictions of  
levels in some be attempted. In addition, this type  
of measurement permits investigation of laws on a logical  
basis. Also, the spectra obtained would possibly be  
analyzed by other engineers to determine the exact order  
of the law and thereby assist in redesigning to  
reduce the stress output of axial-flow fans. Through  
analytical formulas, such as the one presented here, some  
existing specimens should not be used. The  
analysis of any case presented leads to the  
conclusion that the best values of the data

It the test method qualifies on points A, B, and C, (p. 29 ) it is then worthwhile to examine the test setup. In the arrangement used for these tests, it can be seen that the duct and exponential horn, built of standard size materials from simple plans lend themselves to exact reproduction. This fact is important in standardizing an acceptance test procedure. Another point in favor of the system is that it is inexpensive and easy to manufacture.

The final component to be considered in a test method is the measuring system. Again, the results of an examination are favorable for the system employed. Each component is of good accuracy when properly calibrated. None are dependent upon battery power and are therefore quite stable. Furthermore, the necessary calibration is quite simple and requires little time. Finally, the time required to obtain good data is short due to the relatively small swing in the readings afforded by the use of the one-third octave filters as opposed to a sound analyzer. Because one-third octave band filters are not readily available in the United States, full octave-band filters should probably be specified for use in government test facilities.

It has been pointed out in the report that the present position of the...  
 A. B. C. (1952) is...  
 In the...  
 It can be seen that the...  
 of...  
 always to...  
 in...  
 point in...  
 and may to...

The...  
 best...  
 of an...  
 that...  
 period...  
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 education...  
 finally...  
 for...  
 allowed...  
 opposed...  
 hand...  
 States...  
 provided...

The indications are that on all points considered, the proposed method fulfills the requirements. Although the evidence is not conclusive concerning the quality of the data, it is felt that further exploitation of this procedure is warranted because of the simplicity of the setup and the varied types of data obtainable.

The indications are that on all points considered, the proposed method affords the results. Although the evidence is not conclusive concerning the quality of the work, it is felt that further application of this procedure is warranted because of the simplicity of the setup and the varied types of data available.

The following is a summary of the work done during the past few months. It is hoped that this summary will be of some value to those who are interested in the study of the properties of the various types of materials. The work has been done in the laboratory of the Bureau of Standards, and the results are being published in the Journal of Research of the National Bureau of Standards.

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## VI. RECOMMENDATIONS

In the light of the results obtained and the conclusions reached, the following recommendations are suggested relative to further study of the ventilating fan test proposed herein:-

1. The duct system and measuring equipment used in this test, or a similar test setup, should be employed for future investigation.

2. Several other fans should be tested to confirm the accuracy of the overall sound-power formula and to compare the frequency spectrum with those obtained for the  $A\frac{1}{2}$  and the  $Al\frac{1}{2}$  fans. The overall sound-power level formula, as stated in the report (or one derived to give good agreement with measured data for these and other fans), could be used as a design criterion or as an acceptance specification for standard Navy and for commercial ventilating fans.

3. Test  $A\frac{1}{2}$  and  $Al\frac{1}{2}$  fans with a-c drive motors to investigate the effect of motor noise.

4. Higher back pressures in the duct should be arranged for without disturbing the sound field. Investigation of power levels at these increased fan loadings should be made.



RECOMMENDATIONS

In the light of the results obtained and the conclusions reached, the following recommendations are suggested relative to further study of the vibrating fan test project herein:

1. The test system and measuring equipment used in this test, or a similar test setup, should be employed for future investigation.

2. Several other fans should be tested to confirm the accuracy of the overall sound-power levels and to compare the frequency spectrum with those obtained for the  $\frac{1}{2}$  and  $1\frac{1}{2}$  fans. The overall sound-power level results, as stated in the report (or one derived to give good agreement with measured data for fans and other fans), could be used as a design criterion for an appropriate specification for standard fans and for commercial vibrating fans.

3. Test  $\frac{1}{2}$  and  $1\frac{1}{2}$  fans with a-v drive motors to investigate the effect of motor noise.

4. Higher sound velocities in the duct should be investigated without changing the sound field. Investigation of power levels at other locations in the duct should be made.

5. Investigate more fully the effect on sound-pressure level of varying the radial position of the microphone. Check this effect at various speeds and frequencies in order to obtain a relation between radial sound-pressure level variation and fan speed, frequency, and duct dimensions. (The radial change in levels for the  $A\frac{1}{2}$  fan may have been caused by poor motor construction.) Further damping of the duct, using sand, may decrease this effect.

6. Increase measuring duct length and increase the number of duct straightening vanes to reduce possible turbulent effects at the measuring section.

7. Make sound-pressure level measurements at the intake end of the fans and obtain complete directivity data for this end of the fans.

8. In order to obtain frequency data quickly with an adequate degree of frequency selection, at least a one-third octave filter should be used. For a more accurate investigation of the appearance of the fundamental blade frequency and its harmonics in the fan sound output, a frequency analyzer or wave analyzer with a very narrow band should be used.

2. Theoretical work following the method of  
 about-pressure level of varying the radial position  
 of the electrodes. Great care should be taken  
 speeds and frequencies in order to obtain a relation  
 between radial about-pressure level variation and  
 the speed, frequency, and about diameter. The radial  
 distance in levels for the  $\frac{1}{2}$  inch may have been covered  
 by poor motor construction. Further studies of the  
 data being obtained are necessary in this effect.

3. Increased frequency about pressure and  
 between the number of about diameter varies in  
 relation to radial position effects as the operating  
 section.

4. The about-pressure level measurements  
 of the limits and of the area and about diameter  
 directly due to the size and of the area.

5. It is to obtain frequency data  
 directly and an accurate picture of frequency relation.  
 at least a one-third degree linear should be used,  
 for a more accurate investigation of the frequency  
 of the relationship with frequency and the diameter  
 at the about diameter, a frequency relation of  
 with diameter with a very narrow band should be used.

9. The test set-up should be mounted on a rigid foundation (cement floor) to aid in minimizing system vibrations.

10. To eliminate motor noises being transmitted through the duct walls to the measuring section, insert a short (about 2") canvas sleeve between the expansion section and the measuring duct.

11. Test this and other kinds of microphone windscreens to determine more precisely their effect on the frequency spectra and overall power levels.

The windscreen used in this series of tests is shown in PLATE V.

9. The test was run about as described on a  
right hand side (see Fig. 1) to all in  
system.

10. In addition to the test being  
run through the duct into the receiving  
line a short (about 2') length of  
expansion section and the receiving duct.

11. Test runs and other data of  
interest to determine more exactly their effect  
on the frequency spectra and overall power levels.  
The wind tunnel used in this series of tests is shown

in PLATE V.

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Test runs and other data of  
interest to determine more exactly their effect  
on the frequency spectra and overall power levels.  
The wind tunnel used in this series of tests is shown  
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		97.
		98.
		99.
		100.

A. APPARATUS

1. Octave-Band Analyzer, General Radio Company  
Type 1550-A, No. 101.
2. Slide-wire Rheostate (3)
  - (1) 107 Ohm, 3.3 Amps. No. 96737
  - (2) 120 Ohm, 2.5 Amps, No. 3383X, 1748X
3. MIT Acoustics Laboratory Condenser Microphone  
Amplifier AL-167
4. Ballantine Laboratories Voltmeter  
Model 643, No. 196266.
5. One-Third Octave Band Analyzer, Telefon Fabrik  
Automatic A/S and Kobenhaven Filter 11203-4.
6. Strobotac, Type No. 631-B, No. 11071, General  
Radio Company.
7. Motor Control Starting Box, Cutler-Hammer Company.
8. Microphone, Condenser, Type 21-B, Altec-Lansing  
Corporation
9. Simpson Voltmeters (2) Simpson Electric Company  
Chicago, Model 260, Nos. 837130, 837131.
10. Elison Inclined Draft Gage, Elison Company  
Chicago.
11. U. S. Navy Axial-Flow Fan,  $A\frac{1}{2}$  D1W5, Mfr. Ser. No.  
A-8704. Buffalo Forge Company, Buffalo.
12. U. S. Navy Axial-Flow Fan,  $A1\frac{1}{2}$  D1W5, Mfr. Ser. No.  
A-22201. Buffalo Forge Company, Buffalo.



APPENDIX

1. Göttsche-Band Analyser, Bennett Radio Company  
Type 1220-A, No. 101.
2. Eichen-wire Recorder (3)  
(1) 107 Ohm, 2.5 Amps, No. 10737  
(2) 100 Ohm, 2.5 Amps, No. 10738, 1942
3. MIT Scientific Laboratory Condenser Microphone  
Model 62-107
4. Bell Laboratories Volume  
Model 62, No. 10736
5. One-Tone Oscillator, Bell Telephone Laboratories  
Automatic 47 and Condenser Filter 1103-4
6. Oscilloscope, Type 631-E, No. 11071, General  
Radio Company.
7. Radio Control, Standard, General Electric Company.
8. Oscilloscope, Condenser, Type 631-B, Allen-Bassett  
Corporation
9. Eichen Volume (3) - American Electric Company  
Chicago, Model No. 10735, 1941.
10. Eichen Volume (1) - Eichen Company  
Chicago.
11. U. S. Navy Radio-Phone No. 10734, No. 10735, No. 10736  
A-570A, Bell Telephone Company, Chicago.
12. U. S. Navy Radio-Phone No. 10734, No. 10735, No. 10736  
A-5700, Bell Telephone Company, Chicago.

B. DATA1. Calibration Data

## a. System

$$1 \text{ volt} = 1 \text{ dyne/cm}^2$$

$V_{\text{out}}$  = Amplifier Output Voltage

$V_{\text{mic}}$  = Microphone Output Voltage

Response of 21-B microphone to -48.6 db is about -45.5 db

$$20 \log_{10} \frac{V_{\text{mic}}}{1} = -45.5 \text{ db for } 74 \text{ db}$$

$$\log_{10} V_{\text{mic}} = 2.275$$

$$V_{\text{mic}} = \frac{1}{188} = 0.0053 \text{ v for } 74 \text{ db}$$

Line Amplifier Gain = 40 db

$$20 \log_{10} \frac{V_{\text{out}}}{V_{\text{mic}}} = 40 \text{ db,} \quad \frac{V_{\text{out}}}{V_{\text{mic}}} = 100$$

$$V_{\text{out}} (74 \text{ db}) = 0.53 \text{ v}$$

$$V_{\text{out}} (80 \text{ db}) = 1.06 \text{ v}$$

$$\approx 1.0 \text{ v}$$

This gives scale factor for Ballantine Voltmeter

b. Microphone Calibration (See Fig. 7 for frequency calibration of microphone.)

1. Calculation Data

a. Inputs

$$I_{in} = 1 \text{ (unit)}$$

$$V_{out} = \text{Amplifier Output Voltage}$$

$$V_{in} = \text{Reference Output Voltage}$$

Frequency of 20.0 kHz is used for the calculation of the gain.

$$20 \text{ for } \frac{V_{out}}{V_{in}} = -42.5 \text{ dB for } 70 \text{ dB}$$

$$\log_{10} V_{in} = 0.301$$

$$V_{in} = \frac{1}{100} = 0.01 \text{ V for } 70 \text{ dB}$$

Line amplifier gain = 40 dB

$$20 \log_{10} \frac{V_{out}}{V_{in}} = 40 \text{ dB} \Rightarrow \frac{V_{out}}{V_{in}} = 100$$

$$V_{out} (70 \text{ dB}) = 0.70 \text{ V}$$

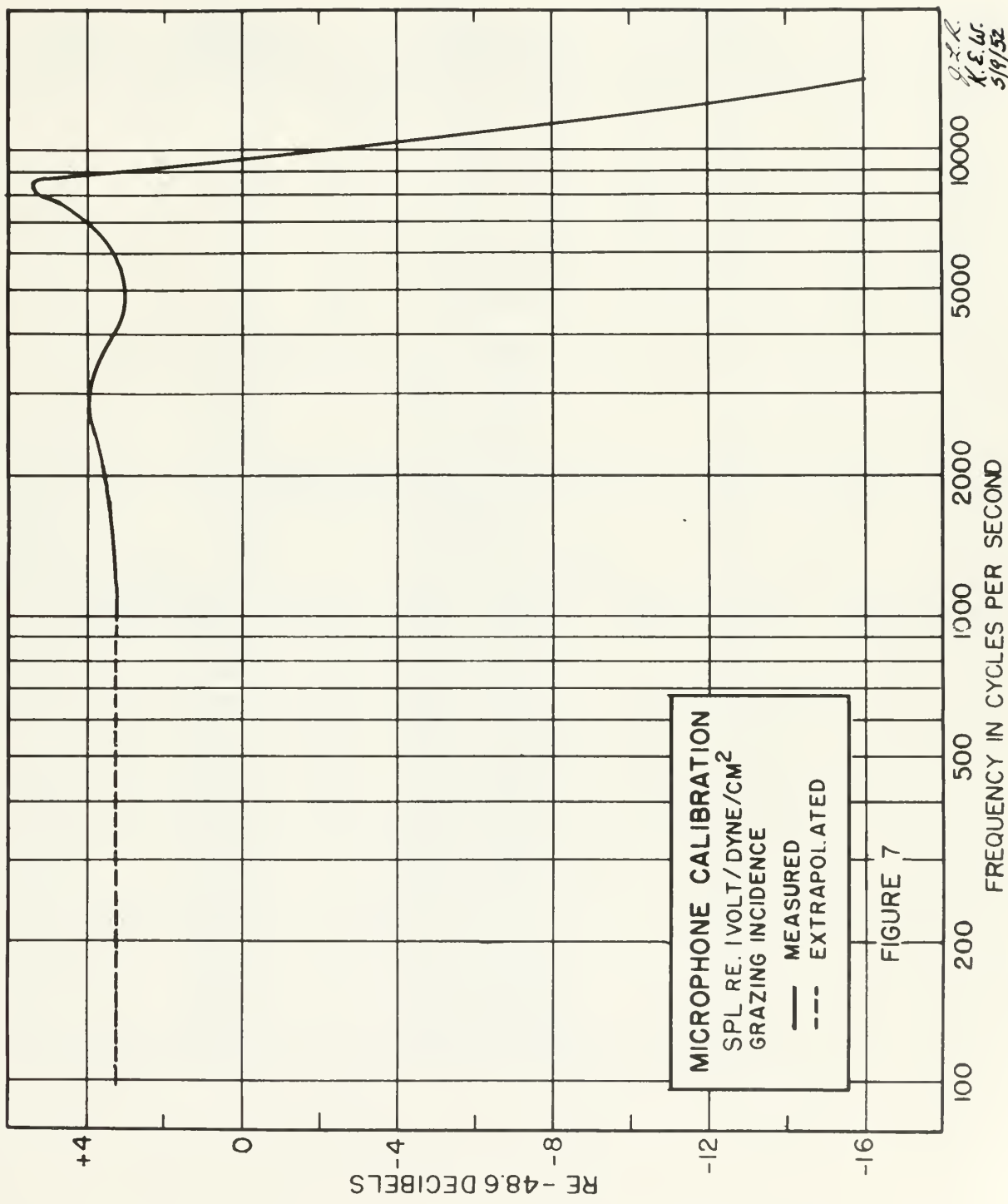
$$V_{out} (50 \text{ dB}) = 0.10 \text{ V}$$

$$\approx 0.1 \text{ V}$$

This table shows the gain for different frequencies.

b. Reference voltage (see Fig. 1 for frequency)

(Calculation of reference)





## c. One-Third Octave Filter Calibration

Band Number	Band Center Frequency	Band Bounding Frequencies	Band Level Correction
1	50	45-57	-4
2	63	57-71	-3
3	80	71-90	-2
4	100	90-114	-2
5	125	114-142	-1
6	160	142-180	-1
7	200	180-228	-1
8	250	228-284	-1
9	320	284-360	-1
10	400	360-456	0
11	500	456-568	0
12	630	568-720	0
13	800	720-912	0
14	1000	912-1136	0
15	1250	1136-1440	0
16	1600	1440-1824	0
17	2000	1824-2272	0
18	2500	2272-2880	0
19	3200	2880-3648	0
20	4000	3648-4544	0
21	5000	4544-5760	-1
22	6300	5760-7296	-1
23	8000	7296-9088	-2
24	10000	9088-11520	-2

## c. One-Third Native Wilds Collection

Plant Number	Plant Number	Plant Number	Plant Number
1	20	25-27	4
2	28	27-29	3
3	30	29-31	2
4	100	30-32	2
5	105	31-33	1
6	100	32-34	1
7	200	33-35	1
8	230	34-36	1
9	250	35-37	1
10	400	36-38	0
11	500	37-39	0
12	630	38-40	0
13	680	39-41	0
14	1000	40-42	0
15	1250	41-43	0
16	1500	42-44	0
17	2000	43-45	0
18	2500	44-46	0
19	3000	45-47	0
20	4000	46-48	0
21	5000	47-49	1
22	6000	48-50	1
23	8000	49-51	2
24	10000	50-52	2

2. Horn Check

Readings of SPL\* at axial positions along horn length, using fan  $A\frac{1}{2}$ .

Axial Horn Position	Speed						
	Ambient	1000	1500	2000	2500	3000	3450
1	48	65	60	62	64	68	69
2	48	65	59	60	64	67	69
3	48	63	57	59	63	66	67.5
4	48	61	57	57	63	62.5	66
5	48	60	57	56.5	61	62	66
6	48	58	57	56	60	60.5	63

\* All readings  $\pm 1.5$  db

$\Delta IL = \Delta SPL$  (Reference Sound-Pressure Level at Horn Throat, Position 2)

$\Delta SPL$ Position	Speed					
	1000	1500	2000	2500	3000	3450
3	-2	-2	-1	-1	-1	-1.5
4	-4	-2	-3	-1	-4.5	-3
5	-5	-2	-3.5	-3	-5	-3
6	-7	-2	-4	-4	-6.5	-6

See Fig. 10, p. A-32



Form 1000

Inventory of 20% of total positions along with  
length, unit for 1/2

Speed

Total Hours  
Position

3450	3000	2500	2000	1500	1000	500	Position
80	80	84	88	90	95	98	1
80	70	84	88	90	95	98	2
87.5	80	83	88	92	95	98	3
88	80.5	83	87	92	95	98	4
88	85	87	88	92	95	98	5
87	80.5	80	88	92	95	98	6

All readings = 1.5 hr

All = 20% (Reference Point-Reference Level at Point  
Through Position 2)

Speed

Total  
Position

3450	3000	2500	2000	1500	1000	500	Position
2.1-1.2	1	1	1	2	2	3	3
2	1.5	1	2	2	4	4	4
2	2	3	2.5	2	2	2	2
2	2.5	4	4	2	2	2	6

See Fig. 10, p. 4-32

3. Radial Check ( $A_2^2$ )

SPL

f	Band	n - 1000				n = 2000				n = 3450								
		0"	3"	6"	8"	0"	3"	6"	8"	0"	1"	2"	3"	4"	5"	6"	7"	8"
100	4	66	66	65	65	75	73	72	72	78	78	78	78	78	78	78	78	78
125	5	63	63	63	63	71	69	68	69	77	77	76	77	77	77	76	76	77
160	6	69	69	69	69	68	69	68	68	75	75	76	75	75	76	76	75	75
200	7	64	65	64	64	68	70	69	69	74	74	74	74	74	74	74	75	75
250	8	63	64	65	66	76	77	76	75	76	76	77	76	76	78	78	78	77
320	9	63	67	73	74	75	75	74	74	78	78	79	78	78	79	79	79	79
400	10	77	84	88	90	72	73	74	74	83	82	82	83	84	84	84	84	84
500	11	71	86	91	94	69	91	76	76	80	80	80	81	81	81	82	82	83
630	12	54	64	70	73	66	67	69	69	78	78	78	79	79	79	79	80	80
800	13	58	57	61	63	74	74	73	76	76	79	80	82	84	85	85	84	87
1000	14	52	54	57	60	71	70	74	74	74	76	77	79	80	80	81	81	82
1250	15	49	56	55	57	64	65	66	68	76	77	78	79	80	80	80	80	81
1600	16	50	51	52	52	65	65	66	67	76	77	79	81	81	81	81	79	80
2000	17	40	43	44	46	60	62	64	67	74	74	74	73	74	76	76	77	79
2500	18	39	41	40	42	58	59	59	61	73	73	72	72	73	74	74	74	75
3200	19	39	38	38	37	54	53	54	55	71	71	71	71	71	71	71	72	72
4000	20	40	39	41	40	51	52	52	52	70	71	70	70	70	71	71	70	70
5000	21	40	39	40	39	51	51	52	52	66	67	67	67	67	67	67	67	67
6300	22	41	41	40	40	52	51	52	53	66	66	66	65	65	65	65	65	65
8000	23	37	37	37	36	49	48	50	49	63	62	62	62	62	62	62	62	62
10000	24	31	31	32	31	46	47	49	47	59	58	58	60	59	59	59	59	58

A-7



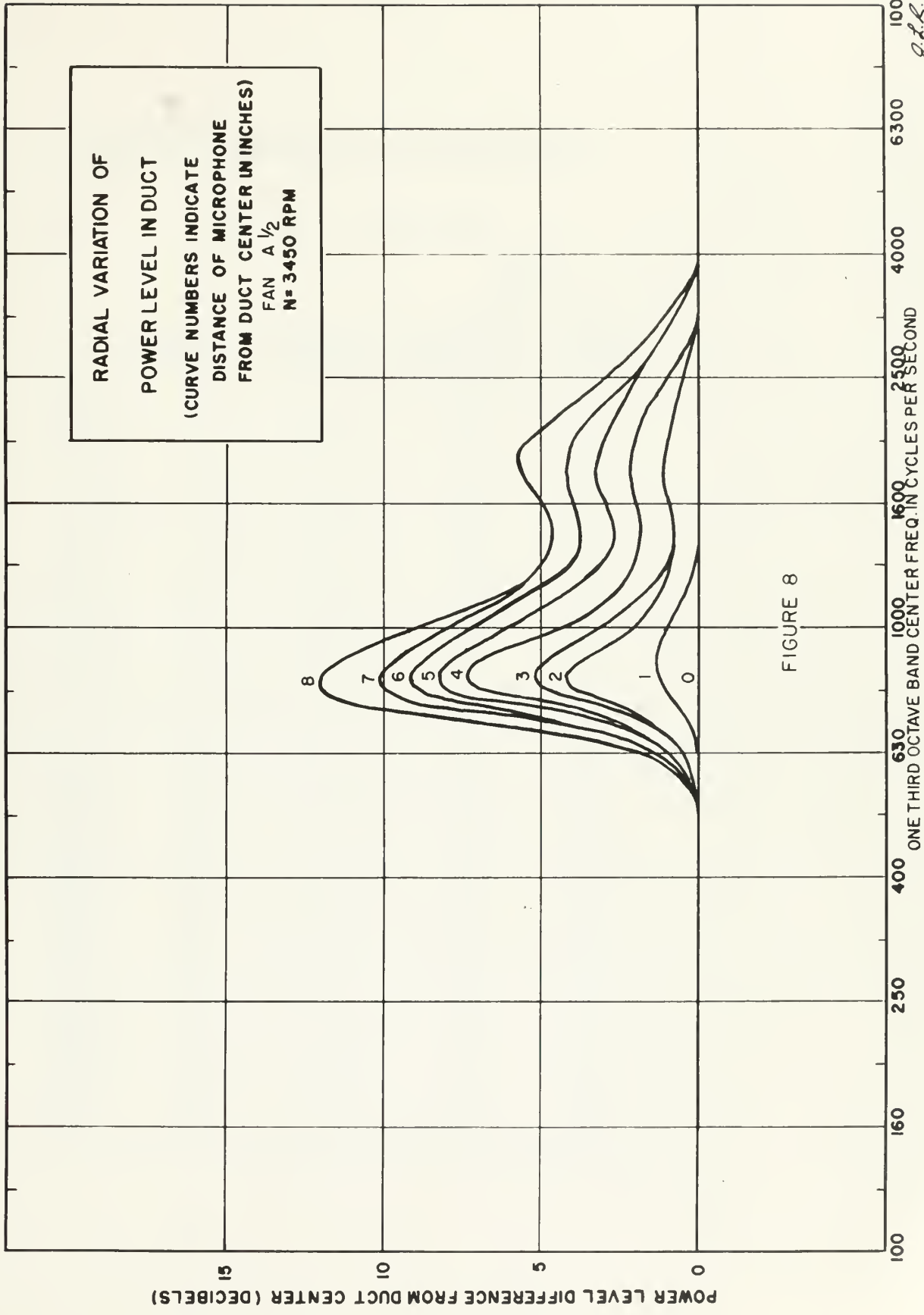


FIGURE 8

P.L.R.  
 K.E.W.  
 5/9/52



4. Effect of Windscreen on Microphone

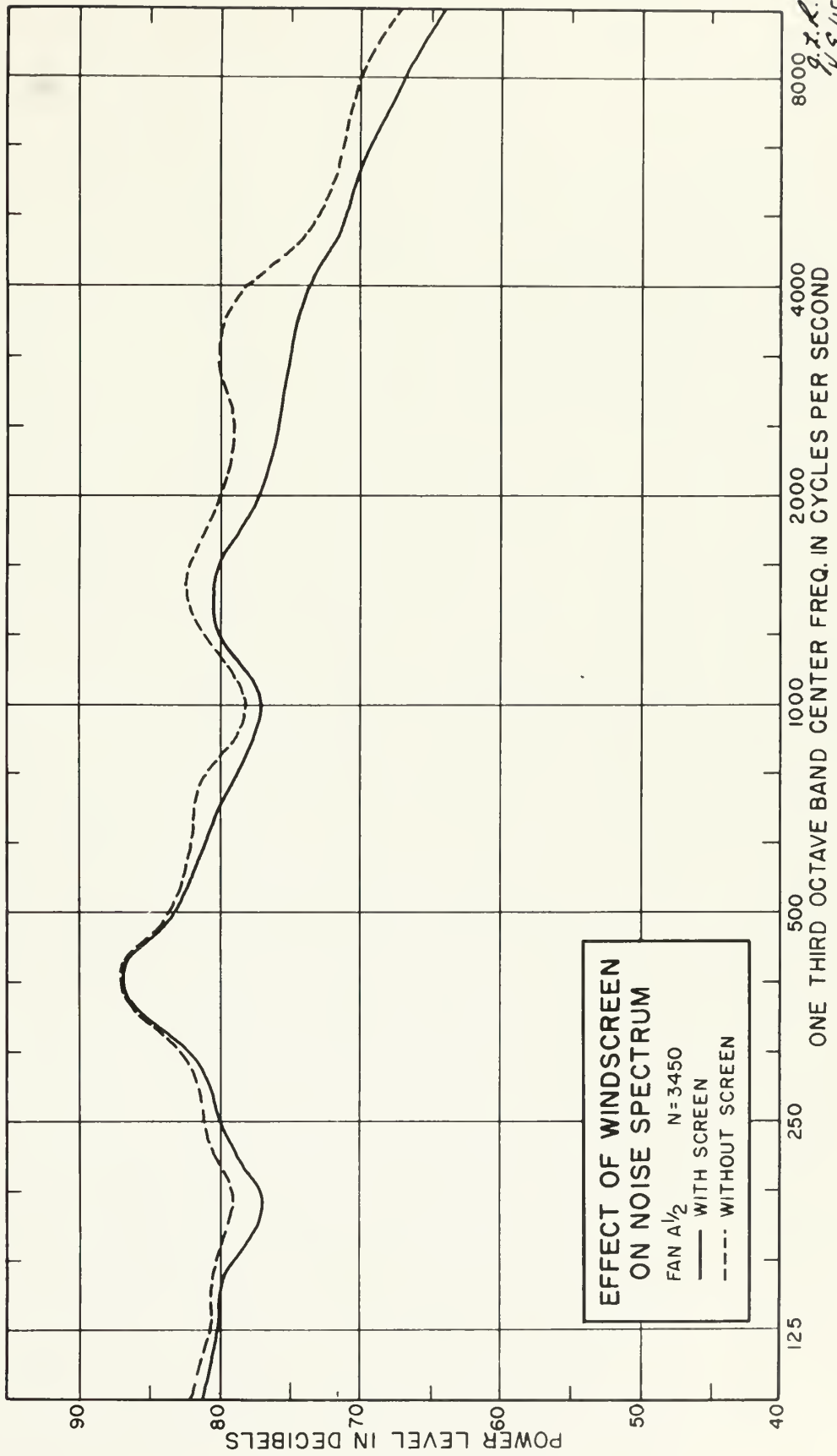
$$A_{\frac{1}{2}}, n = 3450 \text{ RPM}$$

f	Band	Ambient	<u>SPL</u>	
			No Screen	With Screen
100	4	57	78	77
125	5	52	76	76
160	6	57	76	75
200	7	51	75	73
250	8	48	77	76
320	9	50	78	78
400	10	50	83	83
500	11	42	79	79
630	12	40	78	77
800	13	46	77	75
1000	14	41	74	73
1250	15	38	77	76
1600	16	40	78	76
2000	17	37	76	73
2500	18	37	75	72
3200	19	33	76	71
4000	20	26	74	70
5000	21	19	69	67
6300	22	19	67	66
8000	23	19	66	63
10000	24	19	63	60

TABLE 1. SUMMARY OF INVESTMENT DATA

$$I = \frac{1}{r} \sum_{t=1}^n \frac{C_t}{(1+r)^t}$$

Year	Investment	Present Value	NPV
1	100	90.91	-9.09
2	150	121.67	72.58
3	180	139.66	111.64
4	200	153.85	155.49
5	220	165.14	204.34
6	240	173.76	258.58
7	260	179.93	318.51
8	280	183.85	384.64
9	300	185.68	456.57
10	320	185.54	534.00
11	340	183.53	616.83
12	360	179.76	705.06
13	380	174.34	798.79
14	400	167.38	898.02
15	420	158.99	1002.75
16	440	149.28	1113.08
17	460	138.26	1229.01
18	480	126.04	1350.54
19	500	112.73	1477.67
20	520	99.34	1610.40
21	540	85.88	1748.73
22	560	72.36	1892.66
23	580	58.79	2042.19
24	600	45.18	2197.32
25	620	31.54	2358.05
26	640	17.87	2524.38
27	660	4.18	2696.31
28	680	-7.53	2873.84
29	700	-20.07	3057.07
30	720	-31.84	3246.00



9.2.R.  
K.S.W.  
5/9/52

FIGURE 9





5.

 $\frac{1}{A_2}$  Fan Test (No Back Pressure)

Band Center Freq.	Band No.	Spectrum Level Corr.	Ambient	n = 800		900		1000	
				SPL	Spec Level	SPL	Spec Level	SPL	Spec Level
100	4	12.5	57	65	51.5	68	55.5	66	53.5
125	5	15	52	66	51	64	49	63	48
160	6	16	57	63	46	73	57	69	53
200	7	16.5	51	58	40.5	61	44.5	64	47.5
250	8	17.5	48	60	42.5	62	44.5	63	45.5
320	9	18.5	50	73	54.5	72	53.5	63	44.5
400	10	19.5	50	71	51.5	83	63.5	77	57.5
500	11	21	42	58	37	69	48	71	50
630	12	22	40	52	30	57	35	54	32
800	13	23	46	52	28	57	34	58	35
1000	14	24	41	54	30	56	32	52	28
1250	15	25	38	48	23	57	32	49	24
1600	16	26	40	48	21	56	30	50	24
2000	17	27	37	41	12	45	17	42	13
2500	18	28	37	40	9	40	9	41	11
3200	19	29	33	37	6	39	9	40	10
4000	20	30	26	36	6	38	8	40	10
5000	21	30.5	19	38	7.5	39	8.5	40	9.5
6300	22	31	19	39	8	40	9	41	10
8000	23	31.5	19	34	2.5	36	4.5	37	5.5
10000	24	32	19	28	- 4	31	- 1	31	- 1
Overall SPL				0" (On Duct $\phi$ )		82	79	81	
				3"		80	89	88	
				6"		81	88	93	
				8"		82.5	91	95	
Average Overall SPL				81.8	87.7	90.8			

Table 1  
 Fan Test (No Back Pressure)

Band Center Freq.	Band No.	Spectrum Level Corr.	Amplitude	n = 800			900		1000
				SPL Level	SPL Level	SPL Level	SPL Level	SPL Level	
100	4	15.5	27	65	21.5	68	55.5	68	
125	5	15	25	66	21	64	49	63	
160	6	16	27	62	46	73	27	69	
200	7	16.5	21	55	40.5	61	44.5	64	
250	8	17.5	48	60	43.5	62	44.5	63	
320	9	18.5	20	73	24.5	75	23.5	63	
400	10	19.5	20	71	21.5	83	63.5	77	
500	11	21	49	50	27	69	48	71	
630	12	22	40	55	30	27	32	24	
800	13	23	46	55	28	27	34	28	
1000	14	24	41	54	30	26	35	29	
1250	15	25	38	48	23	27	26	49	
1600	16	26	40	60	21	26	30	20	
2000	17	27	37	61	15	42	17	45	
2500	18	28	27	40	9	40	9	41	
3200	19	29	33	37	6	39	9	40	
4000	20	30	26	36	6	38	8	40	
5000	21	30.5	29	35	7.5	39	8.5	40	
6300	22	31	19	32	8	48	9	47	
8000	23	31.5	19	24	5.5	36	4.5	37	
10000	24	32	28	28	4	21	7	31	

Overall SPL  
 0" (on axis)  $\phi$   
 7"  
 6"  
 8"

Average Overall SPL  
 81.8      81.7      84.8

$\frac{1}{2}$  Fan Test (No Back Pressure)

Band Center Freq	n = 1100		1200		1300		1500	
	SPL	Spec Level	SPL	Spec Level	SPL	Spec Level	SPL	Spec Level
100	66	53.5	65	51.5	70	57.5	68	55.5
125	66	51	66	51	64	49	66	51
160	64	47	68	52	69	53	68	52
200	64	47.5	62	45.5	66	49.5	67	50.5
250	64	46.5	64	46.5	68	50.5	72	54.5
320	64	45.5	67	48.5	67	48.5	69	50.5
400	73	53.5	66	46.5	63	43.5	68	48.5
500	82	61	74	53	74	53	64	43
630	68	46	61	39	77	55	66	44
800	58	35	56	33	59	36	60	37
1000	57	33	64	40	56	32	58	34
1250	53	28	57	32	56	31	58	33
1600	52	26	59	33	58	32	60	34
2000	45	17	49	22	49	22	53	26
2500	42	12	46	18	44	16	50	22
3200	42	13	43	14	43	14	46	17
4000	41	11	42	12	43	13	45	15
5000	44	13.5	43	12.5	44	13.5	47	16.5
6300	42	11	44	13	44	13	46	15
8000	40	8.5	42	11.5	41	9.5	43	11.5
10000	36	4	37	5	38	6	40	8
<b>Overall</b>								
SPL	0"	85		79		81		82
	3"	92		82		81		84
	6"	97		89		84		89
	8"	98		92		85		90
<b>Average Overall</b>								
	SPL	92.0		87.0		83.0		86.8

Level	1200		1300		1400		1500		Level
	1200	1200	1300	1300	1400	1400	1500	1500	
100	61	27.3	70	27.3	63	23.2	64	23.2	
115	66	42	64	27	66	27	66	27	
130	60	23	69	29	60	27	63	27	
150	67	40.2	62	40.2	62	47.3	62	47.3	
170	72	50.2	68	50.2	64	46.2	68	46.2	
190	69	45.2	67	48.2	67	45.2	64	45.2	
210	63	41.2	63	46.2	66	33.2	73	33.2	
230	64	22	74	23	74	21	68	21	
250	66	23	77	29	61	40	63	40	
270	60	26	72	23	72	36	68	36	
290	58	26	76	40	64	23	57	23	
310	58	21	76	28	67	28	68	28	
330	60	28	78	23	69	26	72	26	
350	63	28	79	28	72	27	72	27	
370	60	16	74	16	76	16	75	16	
390	50	14	73	14	73	13	73	13	
410	42	13	73	13	73	13	73	13	
430	47	17.2	74	17.2	73	13.2	74	13.2	
450	46	13	74	13	74	11	74	11	
470	43	2.2	77	2.2	76	0.2	76	0.2	
490	40	6	78	2	77	4	78	4	

Overall	Overall	Overall	Overall
62	61	62	62
62	62	62	62
62	62	62	62
62	62	62	62

A $\frac{1}{2}$  Pan Test (No Back Pressure)

Band Center Freq	n = 1700		2000		2300		2600											
	SPL	Spec Level	SPL	Spec Level	SPL	Spec Level	SPL	Spec Level										
100	81	68.5	75	62.5	71	58.5	79	66.5										
125	68	53	71	56	70	55	73	58										
160	68	52	68	52	71	55	71	55										
200	70	53.5	68	51.5	70	53.5	69	52.5										
250	71	53.5	76	58.5	79	61.5	74	56.5										
320	75	56.5	75	56.5	77	58.5	81	62.5										
400	70	50.5	72	52.5	74	54.5	74	54.5										
500	64	43	69	48	75	54	76	55										
630	64	42	66	44	69	47	73	51										
800	67	44	74	51	68	45	69	46										
1000	59	35	71	47	71	47	73	49										
1250	60	35	64	39	66	41	72	47										
1600	62	36	65	39	68	42	71	45										
2000	56	29	60	33	64	37	66	39										
2500	51	23	58	30	62	34	66	38										
3200	49	20	54	25	59	30	63	34										
4000	47	17	51	21	56	26	61	31										
5000	46	15.5	51	20.5	53	22.5	58	27.5										
6300	48	17	52	21	54	23	58	27										
8000	46	14.5	49	17.5	50	18.5	60	28.5										
10000	42	10	46	14	47	15	58	26										
Overall SPL	0"	86	86	87	90	3"	86	88	91	6"	88	89	92	8"	88	87	89	92
Average Ov. SPL		87.0	86.2	88.3	91.3													

Table 1 (continued)

Band Center Freq	1750		2000		2250		Band Center Freq
	Att Level	Att Level	Att Level	Att Level	Att Level	Att Level	
100	81	81	71	71	61	61	100
125	68	68	70	70	66	66	125
150	63	63	71	71	68	68	150
200	70	70	70	70	61.5	61.5	200
250	71	71	70	70	61.8	61.8	250
300	72	72	71	71	61.9	61.9	300
400	70	70	70	70	61.8	61.8	400
500	67	67	72	72	61	61	500
620	64	64	69	69	64	64	620
800	61	61	68	68	61	61	800
1000	58	58	71	71	61	61	1000
1250	60	60	68	68	61	61	1250
1500	63	63	68	68	61	61	1500
2000	58	58	64	64	61	61	2000
2500	57	57	64	64	61	61	2500
3000	48	48	63	63	61	61	3000
4000	47	47	61	61	61	61	4000
5000	46	46	57	57	61.8	61.8	5000
6300	45	45	54	54	61	61	6300
8000	46	46	50	50	61.8	61.8	8000
10000	43	43	47	47	61	61	10000

Overall  
Att. Level

61

61

61

61

Att. Level

61

61

61

61

$\frac{1}{2}$  Fan Test (No Back Pressure)

Band Center Freq	n = 3000		3200		3450	
	SPL	Spec Level	SPL	Spec Level	SPL	Spec Level
100	79	66.5	79	66.5	78	65.5
125	73	58	78	63	77	62
160	74	58	74	58	75	59
200	72	55.5	73	56.5	74	57.5
250	75	57.5	76	58.5	77	59.5
320	78	59.5	79	60.5	78	59.5
400	80	60.5	83	63.5	83	63.5
500	78	57	78	57	79	58
630	77	55	77	55	78	56
800	73	50	76	53	75	52
1000	74	50	73	49	73	49
1250	75	50	76	52	76	51
1600	73	47	75	49	78	52
2000	70	43	72	45	73	46
2500	71	43	70	42	72	44
3200	68	39	70	41	72	43
4000	66	36	68	38	70	40
5000	62	31.5	65	34.5	66	35.5
6300	62	31	66	35	66	35
8000	64	32.5	65	33.5	63	31.5
10000	62	30	62	30	60	28
<b>Overall</b>						
SPL	0"	92	92		93.5	
	3"	93	93		95	
	6"	94	94		95	
	8"	95	95		96	
<b>Average OV. SPL</b>		<b>93.6</b>	<b>93.6</b>		<b>95.0</b>	



Table 1 (continued)

Year	1990		1991		1992	
	Level	Rate	Level	Rate	Level	Rate
1988	68	20	68	20	68	20
1989	68	20	68	20	68	20
1990	68	20	68	20	68	20
1991	68	20	68	20	68	20
1992	68	20	68	20	68	20
1993	68	20	68	20	68	20
1994	68	20	68	20	68	20
1995	68	20	68	20	68	20
1996	68	20	68	20	68	20
1997	68	20	68	20	68	20
1998	68	20	68	20	68	20
1999	68	20	68	20	68	20
2000	68	20	68	20	68	20
2001	68	20	68	20	68	20
2002	68	20	68	20	68	20
2003	68	20	68	20	68	20
2004	68	20	68	20	68	20
2005	68	20	68	20	68	20
2006	68	20	68	20	68	20
2007	68	20	68	20	68	20
2008	68	20	68	20	68	20
2009	68	20	68	20	68	20
2010	68	20	68	20	68	20
2011	68	20	68	20	68	20
2012	68	20	68	20	68	20
2013	68	20	68	20	68	20
2014	68	20	68	20	68	20
2015	68	20	68	20	68	20
2016	68	20	68	20	68	20
2017	68	20	68	20	68	20
2018	68	20	68	20	68	20
2019	68	20	68	20	68	20
2020	68	20	68	20	68	20

Year	Level	Rate	Level	Rate
1988	68	20	68	20
1989	68	20	68	20
1990	68	20	68	20
1991	68	20	68	20
1992	68	20	68	20
1993	68	20	68	20
1994	68	20	68	20
1995	68	20	68	20
1996	68	20	68	20
1997	68	20	68	20
1998	68	20	68	20
1999	68	20	68	20
2000	68	20	68	20
2001	68	20	68	20
2002	68	20	68	20
2003	68	20	68	20
2004	68	20	68	20
2005	68	20	68	20
2006	68	20	68	20
2007	68	20	68	20
2008	68	20	68	20
2009	68	20	68	20
2010	68	20	68	20
2011	68	20	68	20
2012	68	20	68	20
2013	68	20	68	20
2014	68	20	68	20
2015	68	20	68	20
2016	68	20	68	20
2017	68	20	68	20
2018	68	20	68	20
2019	68	20	68	20
2020	68	20	68	20

6.  $\frac{1}{2}$  Fan Test (With Back Pressure)

Band Center Freq	n = 1000		1500		2000	
	SPL	Spec Level	SPL	Spec Level	SPL	Spec Level
100	65	52.5	68	55.5	73	60.5
125	63	48	64	49	70	55
160	70	54	66	50	67	51
200	67	50.5	67	50.5	67	50.5
250	62	44.5	74	46.5	76	58.5
320	62	43.5	68	49.5	75	56.5
400	73	53.5	67	47.5	73	53.5
500	69	48	62	41	67	46
630	54	32	65	43	65	43
800	67	44	59	36	76	53
1000	64	40	58	34	73	49
1250	54	29	58	33	63	38
1600	53	27	60	34	64	38
2000	49	22	54	27	60	33
2500	46	18	52	24	58	30
3200	44	15	50	21	54	25
4000	40	10	49	19	52	22
5000	39	8.5	48	17.5	52	21.5
6300	43	12	50	19	53	22
8000	40	8.5	47	15.5	54	22.5
10000	32	0	44	12	54	22
Overall SPL						
0"		81		82		85
3"		87.5		83		85
6"		93.5		85		86
8"		94		87		86
Average OV. SPL		90.4		85.0		85.5
Back Pressure inches of H <sub>2</sub> O		.06		.10		.16

(continued from page 191)

Depth	1955		1956		Depth
	Temp	Salinity	Temp	Salinity	
1000	20.5	35.5	21.0	35.5	1000
900	20.5	35.5	21.0	35.5	900
800	20.5	35.5	21.0	35.5	800
700	20.5	35.5	21.0	35.5	700
600	20.5	35.5	21.0	35.5	600
500	20.5	35.5	21.0	35.5	500
400	20.5	35.5	21.0	35.5	400
300	20.5	35.5	21.0	35.5	300
200	20.5	35.5	21.0	35.5	200
100	20.5	35.5	21.0	35.5	100
Surface	20.5	35.5	21.0	35.5	Surface
<p>Overall Avg of 1955 20.5 35.5</p> <p>Average 1955 20.5 35.5</p>					
1000	20.5	35.5	21.0	35.5	1000
900	20.5	35.5	21.0	35.5	900
800	20.5	35.5	21.0	35.5	800
700	20.5	35.5	21.0	35.5	700
600	20.5	35.5	21.0	35.5	600
500	20.5	35.5	21.0	35.5	500
400	20.5	35.5	21.0	35.5	400
300	20.5	35.5	21.0	35.5	300
200	20.5	35.5	21.0	35.5	200
100	20.5	35.5	21.0	35.5	100
Surface	20.5	35.5	21.0	35.5	Surface

$A\frac{1}{2}$  Fan Test (With Back Pressure)

Band Center Freq	n = 2500		3000		3450	
	SPL	Spec Level	SPL	Spec Level	SPL	Spec Level
100	74	61.5	75	62.5	75	62.5
125	76	61	71	56	74	59
160	71	55	72	56	73	57
200	69	52.5	69	52.5	72	55.5
250	74	56.5	75	57.5	75	57.5
320	79	60.5	78	59.5	76	57.5
400	73	53.5	83	63.5	81	61.5
500	74	53	79	58	78	57
630	70	48	79	57	78	56
800	68	45	73	50	81	58
1000	79	55	74	50	76	52
1250	72	47	74	49	77	52
1600	69	43	72	46	79	53
2000	66	39	69	42	73	46
2500	64	36	69	41	72	44
3200	62	33	68	39	72	43
4000	58	28	64	34	69	39
5000	54	23.5	60	29.5	64	33.5
6300	57	26	61	30	65	34
8000	58	26.5	62	30.5	63	31.5
10000	57	25	60	28	60	28
<b>Overall</b>						
SPL	0"	87.5	91		93.5	
	3"	88	92		94	
	6"	89	94		94	
	8"	89	95		94	
<b>Average</b>						
OV. SPL		88.3	93.2		93.9	
<b>Back Pressure</b>						
Inches of H <sub>2</sub> O		.21	.275		.325	

THE TEST (WITH BACK SYSTEM)

Level	Level	Level	Level	Level	Level
1000	950	900	850	800	750
950	900	850	800	750	700
900	850	800	750	700	650
850	800	750	700	650	600
800	750	700	650	600	550
750	700	650	600	550	500
700	650	600	550	500	450
650	600	550	500	450	400
600	550	500	450	400	350
550	500	450	400	350	300
500	450	400	350	300	250
450	400	350	300	250	200
400	350	300	250	200	150
350	300	250	200	150	100
300	250	200	150	100	50
250	200	150	100	50	0

Level	Level	Level	Level
1000	950	900	850
950	900	850	800
900	850	800	750
850	800	750	700
800	750	700	650
750	700	650	600
700	650	600	550
650	600	550	500
600	550	500	450
550	500	450	400
500	450	400	350
450	400	350	300
400	350	300	250
350	300	250	200
300	250	200	150
250	200	150	100
200	150	100	50
150	100	50	0

Overall SPL Data at Other Speeds

$\frac{1}{A_2}$ , With Back Pressure - Ambient SPL = 82

	n = 800	900	1100	1200	1300	1800	2200
Overall SPL							
0"	84	85	85	85.5	85	86	87
3"	85	95.5	87	87.5	86	86.5	87.5
6"	86.5	100.5	89	89	90	89.5	88.5
8"	87.5	96.5	90.5	89	92	91.5	90
Overall SPL Corr. for Ambient							
0"	79.5	82	82	83	82	84	85.5
3"	82	95.5	85.5	86	84	84.5	86
6"	84.5	100.5	88	88	89	88.5	87.5
8"	86	96.5	90	88	91.5	91.0	90
Av. OV. SPL	83.3	95.6	86.8	86.5	87.4	87.4	87.4
Back Press. in. of H <sub>2</sub> O	.045	.05	.07	.08	.09	.13	.18



7.

A1 $\frac{1}{2}$  Fan Test, (No Back Pressure)

Band Center Freq	Band No.	Spectrum Level Corr.	Ambient	n = 800		900		1000		
				SPL	Spec Level	SPL	Spec Level	SPL	Spec Level	
100	4	12.5	61	81	69.5	72	59.5	71	58.5	
125	5	15	56	70	45	68	53	70	55	
160	6	16	56	65	49	65	49	66	51	
200	7	16.5	52	63	46.5	65	48.5	65	48.5	
250	8	17.5	48	64	46.5	66	48.5	66	48.5	
320	9	18.5	49	66	47.5	64	45.5	64	45.5	
400	10	19.5	50	59	39.5	60	40.5	62	42.5	
500	11	21	43	61	40.0	58	37	61	40	
630	12	22	40	53	31	54	32	56	34	
800	13	23	46	54	31	56	33	56	33	
1000	14	24	42	58	34	59	35	61	37	
1250	15	25	40	56	31	59	34	60	35	
1600	16	26	41	55	29	58	32	60	34	
2000	17	27	40	50	23	53	26	55	28	
2500	18	28	42	46	18	47	19	48	20	
3200	19	29	37	44	15	48	18	49	20	
4000	20	30	34	45	15	46	16	48	18	
5000	21	30.5	29	40	9.5	40	9.5	40	9.5	
6300	22	31	26	35	4	37	6	36	5	
8000	23	31.5	26	33	1.5	35	3.5	36	4.5	
10000	24	32	20	32	0	33	1	34	2	
Overall SPL				0"	82		82		81	
				3"	84		81		82	
				6"	84		82		83	
				8"	85		83		84	
Average Overall SPL			73.0	83.8		82		82.5		
Current (amps)					2.4		2.42		2.43	
Voltage					14.2		15.1		16.9	



1 1/2 inch (No. 1000) (No. 1000)

7.

Overall Level	Overall Elev.	Overall Elev.	n = 800		Overall Elev.	Overall Elev.	Overall Elev.	Overall Elev.
			Top Level	Bot. Level				
1000	71	72	73	74	75	76	77	78
950	71	72	73	74	75	76	77	78
900	71	72	73	74	75	76	77	78
850	71	72	73	74	75	76	77	78
800	71	72	73	74	75	76	77	78
750	71	72	73	74	75	76	77	78
700	71	72	73	74	75	76	77	78
650	71	72	73	74	75	76	77	78
600	71	72	73	74	75	76	77	78
550	71	72	73	74	75	76	77	78
500	71	72	73	74	75	76	77	78
450	71	72	73	74	75	76	77	78
400	71	72	73	74	75	76	77	78
350	71	72	73	74	75	76	77	78
300	71	72	73	74	75	76	77	78
250	71	72	73	74	75	76	77	78
200	71	72	73	74	75	76	77	78
150	71	72	73	74	75	76	77	78
100	71	72	73	74	75	76	77	78

$A\frac{1}{2}$  Fan Test (No Back Pressure)

Band Center Freq	n = 1100		1200		1300		1500	
	SPL	Spec Level	SPL	Spec Level	SPL	Spec Level	SPL	Spec Level
100	72	59.5	75	62.5	78	65.5	79	66.5
125	73	58	73	58	73	58	72	57
160	68	52	70	54	73	57	75	59
200	66	49.5	67	50.5	67	50.5	69	52.5
250	68	50.5	70	52.5	69	51.5	71	53.5
320	65	46.5	68	49.5	68	49.5	71	52.5
400	65	45.5	65	45.5	65	45.5	66	46.5
500	61	40	62	41	63	42	68	47
630	57	45	59	37	60	38	62	41
800	58	45	59	36	59	36	62	40
1000	63	39	62	38	64	40	65	42
1250	60	35	61	36	62	37	65	40
1600	60	34	62	36	63	37	65	39
2000	58	31	59	32	61	34	64	37
2500	50	22	52	24	53	25	58	30
3200	51	22	53	24	53	24	54	25
4000	49	19	50	20	51	21	53	23
5000	42	11.5	43	12.5	45	14.5	47	16.5
6300	38	7	39	8	40	9	43	12
8000	37	5.5	37	5.5	39	7.5	42	10.5
10000	35	3	34.5	2.5	35	3	37	5

## Overall SPL

0"	84	84	84.5	86
3"	84.5	84	85	86
6"	85	83.5	85	86
8"	85	83.5	86	87
Aver. Ov. SPL	84.7	83.8	85.2	86.2

Current (amps)	2.44	2.55	2.6	2.78
Voltage	18.2	19.5	21.0	24.3

Table 1. Loss (No. Base Processes)

Time	1000		1500		2000		2500	
	Level	Time	Level	Time	Level	Time	Level	Time
1000	33	3	33	3.3	34.3	3	33	3
2000	37	3	34	3.3	37	3.3	37	3
3000	42	3	39	3.3	41	3.3	42	3
4000	47	3	44	3.3	46	3.3	47	3
5000	52	3	49	3.3	51	3.3	52	3
6000	57	3	54	3.3	56	3.3	57	3
7000	62	3	59	3.3	61	3.3	62	3
8000	67	3	64	3.3	66	3.3	67	3
9000	72	3	69	3.3	71	3.3	72	3
10000	77	3	74	3.3	76	3.3	77	3
11000	82	3	79	3.3	81	3.3	82	3
12000	87	3	84	3.3	86	3.3	87	3
13000	92	3	89	3.3	91	3.3	92	3
14000	97	3	94	3.3	96	3.3	97	3
15000	102	3	99	3.3	101	3.3	102	3
16000	107	3	104	3.3	106	3.3	107	3
17000	112	3	109	3.3	111	3.3	112	3
18000	117	3	114	3.3	116	3.3	117	3
19000	122	3	119	3.3	121	3.3	122	3
20000	127	3	124	3.3	126	3.3	127	3
21000	132	3	129	3.3	131	3.3	132	3
22000	137	3	134	3.3	136	3.3	137	3
23000	142	3	139	3.3	141	3.3	142	3
24000	147	3	144	3.3	146	3.3	147	3
25000	152	3	149	3.3	151	3.3	152	3
26000	157	3	154	3.3	156	3.3	157	3
27000	162	3	159	3.3	161	3.3	162	3
28000	167	3	164	3.3	166	3.3	167	3
29000	172	3	169	3.3	171	3.3	172	3
30000	177	3	174	3.3	176	3.3	177	3
31000	182	3	179	3.3	181	3.3	182	3
32000	187	3	184	3.3	186	3.3	187	3
33000	192	3	189	3.3	191	3.3	192	3
34000	197	3	194	3.3	196	3.3	197	3
35000	202	3	199	3.3	201	3.3	202	3
36000	207	3	204	3.3	206	3.3	207	3
37000	212	3	209	3.3	211	3.3	212	3
38000	217	3	214	3.3	216	3.3	217	3
39000	222	3	219	3.3	221	3.3	222	3
40000	227	3	224	3.3	226	3.3	227	3
41000	232	3	229	3.3	231	3.3	232	3
42000	237	3	234	3.3	236	3.3	237	3
43000	242	3	239	3.3	241	3.3	242	3
44000	247	3	244	3.3	246	3.3	247	3
45000	252	3	249	3.3	251	3.3	252	3
46000	257	3	254	3.3	256	3.3	257	3
47000	262	3	259	3.3	261	3.3	262	3
48000	267	3	264	3.3	266	3.3	267	3
49000	272	3	269	3.3	271	3.3	272	3
50000	277	3	274	3.3	276	3.3	277	3

Control Level

Control Level	Loss (No. Base Processes)	Time
33	3	3
34.3	3.3	3.3
37	3.3	3.3
41	3.3	3.3
46	3.3	3.3
51	3.3	3.3
56	3.3	3.3
61	3.3	3.3
66	3.3	3.3
71	3.3	3.3
76	3.3	3.3
81	3.3	3.3
86	3.3	3.3
91	3.3	3.3
96	3.3	3.3
101	3.3	3.3
106	3.3	3.3
111	3.3	3.3
116	3.3	3.3
121	3.3	3.3
126	3.3	3.3
131	3.3	3.3
136	3.3	3.3
141	3.3	3.3
146	3.3	3.3
151	3.3	3.3
156	3.3	3.3
161	3.3	3.3
166	3.3	3.3
171	3.3	3.3
176	3.3	3.3
181	3.3	3.3
186	3.3	3.3
191	3.3	3.3
196	3.3	3.3
201	3.3	3.3
206	3.3	3.3
211	3.3	3.3
216	3.3	3.3
221	3.3	3.3
226	3.3	3.3
231	3.3	3.3
236	3.3	3.3
241	3.3	3.3
246	3.3	3.3
251	3.3	3.3
256	3.3	3.3
261	3.3	3.3
266	3.3	3.3
271	3.3	3.3
276	3.3	3.3
281	3.3	3.3
286	3.3	3.3
291	3.3	3.3
296	3.3	3.3
301	3.3	3.3

$Al\frac{1}{2}$  Fan Test (No Back Pressure)

Band Center Freq	n = 1700		2000		2300		2500	
	SPL	Spec Level	SPL	Spec Level	SPL	Spec Level	SPL	Spec Level
100	75	67.5	82	62.5	76	63.5	80	67.5
125	73	58	75	60	75	60	79	64
160	73	57	74	58	75	59	75	59
200	74	57.5	73	56.5	74	57.5	74	57.5
250	72	54.5	74	56.5	79	61.5	82	63.5
320	72	53.5	74	55.5	76	57.5	78	59.5
400	70	50.5	72	52.5	75	55.5	75	55.5
500	68	47	68	47	72	51	74	53
630	65	43	69	47	71	49	71	49
800	64	41	68	45	71	48	72	49
1000	68	34	74	50	74	50	77	53
1250	68	33	73	48	75	50	77	52
1600	65	39	69	43	71	45	73	47
2000	66	39	69	42	71	44	74	47
2500	63	35	68	40	70	42	73	45
3200	58	29	64	35	69	40	73	44
4000	56	26	60	30	67	37	72	42
5000	50	19.5	55	24.5	59	28.5	65	34.5
6300	47	16	52	21	55	24	60	29
8000	45	14.5	50	18.5	54	22.5	58	26.5
10000	40	8	44	12	48	16	53	21

## Overall SPL

0"	86.5	92	92.5	93
3"	86.5	92	93	92.5
6"	86.5	91.5	93	93
8"	87	91.5	93	93
Average Overall SPL	86.6	91.8	92.9	92.9

Current (amps)	2.9	3.05	3.4	3.55
Voltage	27.9	33.3	39.9	45.9

TABLE 1 (continued)

Order	n = 1700		n = 3300		n = 5000		Order
	AVL	AVL	AVL	AVL	AVL	AVL	
10000	40	8	48	11	48	24	28
8000	45	14.5	54	10.5	54	24	28.5
6000	47	16	56	10	56	24	29
4000	52	22	61	9	61	24	29.5
3000	58	28	67	8	67	24	30
2000	66	34	74	7	74	24	30.5
1500	73	40	81	6	81	24	31
1000	82	46	89	5	89	24	31.5
800	90	52	97	4	97	24	32
600	98	58	105	3	105	24	32.5
400	106	64	113	2	113	24	33
300	114	70	121	1	121	24	33.5
200	122	76	129	1	129	24	34
150	130	82	137	1	137	24	34.5
100	138	88	145	1	145	24	35
50	146	94	153	1	153	24	35.5
25	154	100	161	1	161	24	36
10	162	106	169	1	169	24	36.5
5	170	112	177	1	177	24	37

Overall AVL

Overall AVL	AVL	AVL	AVL	AVL
57.9	34.9	34.9	34.9	34.9
7.5	3.6	3.6	3.6	3.6
86.4	86.4	86.4	86.4	86.4
86.4	86.4	86.4	86.4	86.4
86.4	86.4	86.4	86.4	86.4
86.4	86.4	86.4	86.4	86.4

$A\frac{1}{2}$  Fan Test (No Back Pressure)

Band Center Freq	n = 2600		3000		3200		3450	
	SPL	Spec Level	SPL	Spec Level	SPL	Spec Level	SPL	Spec Level
100	78	65.5	85	72.5	98	85.5	87	74.5
125	77	62	83	68	87	72	80	65
160	77	61	77	61	80	64	79	63
200	76	59.5	76	59.5	78	61.5	78	61.5
250	80	62.5	78	60.5	79	61.5	80	62.5
320	78	59.5	79	60.5	80	61.5	81	62.5
400	75	55.5	77	57.5	79	59.5	83	63.5
500	74	53	76	55	78	57	82	61
630	71	49	74	52	77	55	79	57
800	72	49	74	51	76	53	78	55
1000	76	52	79	55	81	57	84	60
1250	77	52	79	54	80	55	82	57
1600	73	47	78	52	78	52	79	53
2000	72	45	76	49	77	50	78	51
2500	70	42	73	45	74	46	76	48
3200	70	41	72	43	73	44	74	45
4000	70	40	75	45	76	46	77	47
5000	63	32.5	70	39.5	73	42.5	76	45.5
6300	59	28	63	32	66	35	70	39
8000	56	24.5	61	29.5	63	31.5	65	33.5
10000	52	20	56	24	58	26	61	29
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Overall SPL								
0"		92.5		94		102		97
3"		92.5		94		102		97
6"		92.5		95		102		96
8"		93		96		102		96
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Average Overall SPL		92.6		94.8		102		96.5
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Current (amps)		3.76		4.04		4.25		4.6
Voltage		48.8		55		60		70

Year	1950		1951		1952		Total
	Yr.	Days	Yr.	Days	Yr.	Days	
1950	75	88.2	80	77.1	82	82.2	245
1951	77	75	84	80	87	80.8	248
1952	79	84	80	81	77	81	236
1953	78	81.5	78	79.5	76	79.5	232
1954	80	81.5	79	80.5	78	80.5	237
1955	87	81.5	80	80.5	79	80.5	246
1956	83	80.5	79	77.5	77	79.5	239
1957	85	81	78	79	76	81	240
1958	79	82	77	78	74	79	230
1959	78	83	76	77	74	78	228
1960	84	81	81	82	79	82	246
1961	82	82	80	84	79	82	246
1962	79	81	78	82	78	81	239
1963	78	80	77	83	76	82	234
1964	76	84	74	84	73	84	237
1965	74	84	73	83	72	83	230
1966	77	86	76	85	75	86	238
1967	75	85.5	73	86.5	70	85.5	231
1968	70	82	69	85	63	82	224
1969	68	81.5	63	80.5	63	81.5	212
1970	67	80	62	81	60	80	209

Year	Total	Average	Overall
1950	245	80.8	81.5
1951	248	80.8	81.5
1952	236	80.8	81.5
1953	232	80.8	81.5
1954	237	80.8	81.5
1955	246	80.8	81.5
1956	239	80.8	81.5
1957	240	80.8	81.5
1958	230	80.8	81.5
1959	228	80.8	81.5
1960	246	80.8	81.5
1961	246	80.8	81.5
1962	239	80.8	81.5
1963	234	80.8	81.5
1964	237	80.8	81.5
1965	230	80.8	81.5
1966	238	80.8	81.5
1967	231	80.8	81.5
1968	224	80.8	81.5
1969	212	80.8	81.5
1970	209	80.8	81.5

A1 $\frac{1}{2}$  Fan Test (No Back Pressure)

Band Center Freq	n = 3800		4200		4600	
	SPL	Spec Level	SPL	Spec Level	SPL	Spec Level
100	84	71.5	81	68.5	81	68.5
125	82	67	83	68	83	68
160	80	64	80	64	81	65
200	78	61.5	79	62.5	80	63.5
250	81	63.5	81	63.5	81	63.5
320	79	60.5	82	63.5	82	63.5
400	81	61.5	83	63.5	82	62.5
500	81	60	82	61	86	65
630	80	58	81	59	83	61
800	80	57	82	59	83	60
1000	83	59	84	60	87	63
1250	83	58	85	60	88	63
1600	81	55	82	56	85	59
2000	80	53	82	55	83	56
2500	78	50	80	52	81	53
3200	75	46	78	49	79	50
4000	78	48	79	49	80	50
5000	78	47.5	79	48.5	80	49.5
6300	74	43	77	46	79	48
8000	69	37.5	73	41.5	76	44.5
10000	63	31	68	36	71	39

## Overall SPL

0"	97.5	99.5	100
3"	97	99.5	100.5
6"	97.5	100	101
8"	97.5	100	101.5
Average Overall SPL	97.4	99.8	100.8
Current (amps)	5.0	5.6	6.1
Voltage	78	90	104



Year	Age	Year	Age	Year	Age	Year	Age
1700	63	1701	64	1702	65	1703	66
1704	67	1705	68	1706	69	1707	70
1708	74	1709	75	1710	76	1711	77
1712	81	1713	82	1714	83	1715	84
1716	88	1717	89	1718	90	1719	91
1720	95	1721	96	1722	97	1723	98
1724	102	1725	103	1726	104	1727	105
1730	110	1731	111	1732	112	1733	113
1736	117	1737	118	1738	119	1739	120
1740	124	1741	125	1742	126	1743	127
1746	133	1747	134	1748	135	1749	136
1750	140	1751	141	1752	142	1753	143
1754	147	1755	148	1756	149	1757	150
1760	156	1761	157	1762	158	1763	159
1766	165	1767	166	1768	167	1769	168
1770	172	1771	173	1772	174	1773	175
1774	179	1775	180	1776	181	1777	182
1778	186	1779	187	1780	188	1781	189
1782	193	1783	194	1784	195	1785	196
1786	200	1787	201	1788	202	1789	203
1790	210	1791	211	1792	212	1793	213
1794	217	1795	218	1796	219	1797	220
1798	224	1799	225	1800	226	1801	227

Year	Age	Year	Age
1700	63	1750	110
1705	68	1755	115
1710	73	1760	120
1715	78	1765	125
1720	83	1770	130
1725	88	1775	135
1730	93	1780	140
1735	98	1785	145
1740	103	1790	150
1745	108	1795	155
1750	113	1800	160

8.

 $A\frac{1}{2}$  Fan Test (With Back Pressure)

Band Center Freq	Band No.	Spectrum Level Corr.	Ambient	n = 800		900		1000	
				SPL	Spec Level	SPL	Spec Level	SPL	Spec Level
100	4	12.5	60	76	63.5	75	62.5	75	62.5
125	5	15	55	67	52	68	53	70	55
160	6	16	50	65	49	62	46	63	47
200	7	16.5	47	59	42.5	62	45.5	61	44.5
250	8	17.5	44	60	42.5	62	44.5	64	46.5
320	9	18.5	41	59	40.5	60	41.5	61	42.5
400	10	19.5	50	55	35.5	57	37.5	59	39.5
500	11	21	40	59	38	59	38.0	59	38
630	12	22	35	51	29	55	33	55	33
800	13	23	40	51	28	52	29	55	32
1000	14	24	37	55	31	57	33	60	36
1250	15	25	33	53	28	55	30	58	33
1600	16	26	33	56	30	55	29	56	30
2000	17	27	30	48	21	51	24	52	25
2500	18	28	29	42	14	43	15	45	17
3200	19	29	35	43	14	45	16	47	18
4000	20	30	32	43.5	13.5	45	15	47	17
5000	21	30.5	28	38	7.5	39	8.5	40	9.5
6300	22	31	20	31	0	32.5	1.5	33	2
8000	23	31.5	20	32	0.5	33.5	2	35	3.5
10000	24	32	19	31	-1	33	1	34	2
Overall SPL					81		81		82
					3"		82		82
					6"		82		82
					8"		82		81
Average Overall SPL					80.9		81.8		81.8
Current (amps)					2.54		2.59		2.62
Voltage					15		16.5		17.8
Back Pressure					.09		.10		.12

Table 1. (continued)

Band Center Freq.	Band Width (Hz)	Station		Station		Station	
		Level (dB)	Level (dB)	Level (dB)	Level (dB)	Level (dB)	Level (dB)
1000	24	10	21	-1	22	1	30
800	23	11.2	20	0.2	23.2	0	30
600	22	12	19	1.2	20	1.2	40
400	20	20	17.2	17.2	16	12	42
200	12	22	15	14	13	10	41
100	4	22.5	13	12	11	8	38
1200	24	10	21	-1	22	1	30
1000	24	10	21	-1	22	1	30
800	23	11.2	20	0.2	23.2	0	30
600	22	12	19	1.2	20	1.2	40
400	20	20	17.2	17.2	16	12	42
200	12	22	15	14	13	10	41
100	4	22.5	13	12	11	8	38
Overall Avg.		10.5	19.5	0.5	21.5	0.5	30.5
Average Overall		10.5	19.5	0.5	21.5	0.5	30.5
Station (avg)		10.5	19.5	0.5	21.5	0.5	30.5
Station		10.5	19.5	0.5	21.5	0.5	30.5
Back Frequency		10.5	19.5	0.5	21.5	0.5	30.5

A1 $\frac{1}{2}$  Fan Test (With Back Pressure)

Band Center Freq.	n = 1100		1200		1300		1500	
	SPL	Spec Level	SPL	Spec Level	SPL	Spec Level	SPL	Spec Level
100	78	65.5	77	64.5	85	72.5	78	65.5
125	74	59	73	58	73	62	72	57
160	65	49	70	54	74	58	71	55
200	62	45.5	63	46.5	65	48.5	67	50.5
250	66	48.5	65	47.5	66	48.5	68	50.5
320	63	44.5	64	45.5	67	48.5	70	51.5
400	60	40.5	62	42.5	62	42.5	66	46.5
500	59	38	60	39	65	44	67	46
630	56	34	58	36	60	38	62	40
800	56	33	57	34	59	36	62	39
1000	61	37	61	37	63	39	65	41
1250	61	36	62	37	63	38	65	40
1600	60	34	64	38	64	38	64	36
2000	54	27	56	29	58	31	62	35
2500	47	19	50	22	51	23	55	27
3200	48.5	19.5	51	22	51	22	55	26
4000	48	18	51	21	51	21	54	24
5000	41	11.5	43	12.5	44	13.5	48	17.5
6300	35	4	37	6	38	7	42	11
8000	36	4.5	37	5.5	37.5	6	41.5	10
10000	36	4	37	5	36.5	3.5	39	7
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Overall SPL								
	0"	82		88		90		85
	3"	83		87		90		85
	6"	83		86.5		91		85.5
	8"	82		87		90		85.5
<hr/>								
Average Overall SPL		82.5		87.2		90.2		85.3
<hr/>								
Current (amps)		2.71		2.79		2.85		3.0
Voltage		19.7		21.4		22.6		26.1
Back Pressure		.135		.15		.165		.195

TABLE 1.1 (continued)

Level	1990		1991		1992		Total
	1990	1991	1990	1991	1990	1991	
100	78	80	82	85	88	90	800
102	77	79	81	84	87	89	790
104	76	78	80	83	86	88	780
106	75	77	79	82	85	87	770
108	74	76	78	81	84	86	760
110	73	75	77	80	83	85	750
112	72	74	76	79	82	84	740
114	71	73	75	78	81	83	730
116	70	72	74	77	80	82	720
118	69	71	73	76	79	81	710
120	68	70	72	75	78	80	700
122	67	69	71	74	77	79	690
124	66	68	70	73	76	78	680
126	65	67	69	72	75	77	670
128	64	66	68	71	74	76	660
130	63	65	67	70	73	75	650
132	62	64	66	69	72	74	640
134	61	63	65	68	71	73	630
136	60	62	64	67	70	72	620
138	59	61	63	66	69	71	610
140	58	60	62	65	68	70	600
142	57	59	61	64	67	69	590
144	56	58	60	63	66	68	580
146	55	57	59	62	65	67	570
148	54	56	58	61	64	66	560
150	53	55	57	60	63	65	550
152	52	54	56	59	62	64	540
154	51	53	55	58	61	63	530
156	50	52	54	57	60	62	520
158	49	51	53	56	59	61	510
160	48	50	52	55	58	60	500
162	47	49	51	54	57	59	490
164	46	48	50	53	56	58	480
166	45	47	49	52	55	57	470
168	44	46	48	51	54	56	460
170	43	45	47	50	53	55	450
172	42	44	46	49	52	54	440
174	41	43	45	48	51	53	430
176	40	42	44	47	50	52	420
178	39	41	43	46	49	51	410
180	38	40	42	45	48	50	400
182	37	39	41	44	47	49	390
184	36	38	40	43	46	48	380
186	35	37	39	42	45	47	370
188	34	36	38	41	44	46	360
190	33	35	37	40	43	45	350
192	32	34	36	39	42	44	340
194	31	33	35	38	41	43	330
196	30	32	34	37	40	42	320
198	29	31	33	36	39	41	310
200	28	30	32	35	38	40	300

Overall	1990	1991	1992	Total
Average	55.5	57.5	59.5	57.5
Standard Deviation	10.0	10.5	11.0	10.5
Minimum	28	30	32	28
Maximum	90	90	90	90

$Al\frac{1}{2}$  Fan Test (With Back Pressure)

Band Center Freq	n = 1700		2000		2300		2500	
	SPL	Spec Level	SPL	Spec Level	SPL	Spec Level	SPL	Spec Level
100	74	61.5	81	68.5	77	64.5	79	66.5
125	73	58	75	60	75	60	77	62
160	72	56	73	57	74	58	75	59
200	70	53.5	75	58.5	74	57.5	75	58.5
250	70	52.5	73	55.5	76	58.5	80	62.5
320	69	50.5	71	52.5	73	54.5	76	57.5
400	68	48.5	69	49.5	71	51.5	72	52.5
500	69	48	68	47	71	50	72	51
630	65	43	68	46	70	48	71	49
800	63	40	67	44	70	47	71	48
1000	67	43	73	49	74	50	77	53
1250	67	42	72	47	74	49	76	51
1600	66	40	69	43	71	45	72	46
2000	65	38	69	42	70	43	72	45
2500	58	30	65	37	69	41	70	42
3200	57	28	61	32	65	36	67	38
4000	57	27	60	30	64	34	66	36
5000	50	19.5	55	24.5	58	27.5	61	30.5
6300	45	14	50	19	54	23	56	25
8000	43	12.5	47	15.5	52	20.5	54	22.5
10000	40	8	43	11	47	15	50	18
<hr/>								
Overall SPL								
	0"	85		94		92		92
	3"	86		93.5		93		92
	6"	87.5		94		93		91
	8"	88		94		93		93
<hr/>								
Average Overall SPL		86.8		93.9		92.8		92.5
<hr/>								
Current (amps)		3.21		3.55		3.8		4.1
Voltage		30.2		36.8		43.8		49.9
Back Pressure		.23		.27		.325		.36

TABLE 1. (continued)

Year	1970		1980		1990		Year
	Level	Est.	Level	Est.	Level	Est.	
1960	11	11	11	11	10	10	1995
1961	11	11	11	11	10	10	1996
1962	11	11	11	11	10	10	1997
1963	11	11	11	11	10	10	1998
1964	11	11	11	11	10	10	1999
1965	11	11	11	11	10	10	2000
1966	11	11	11	11	10	10	2001
1967	11	11	11	11	10	10	2002
1968	11	11	11	11	10	10	2003
1969	11	11	11	11	10	10	2004
1970	11	11	11	11	10	10	2005
1971	11	11	11	11	10	10	2006
1972	11	11	11	11	10	10	2007
1973	11	11	11	11	10	10	2008
1974	11	11	11	11	10	10	2009
1975	11	11	11	11	10	10	2010
1976	11	11	11	11	10	10	2011
1977	11	11	11	11	10	10	2012
1978	11	11	11	11	10	10	2013
1979	11	11	11	11	10	10	2014
1980	11	11	11	11	10	10	2015
1981	11	11	11	11	10	10	2016
1982	11	11	11	11	10	10	2017
1983	11	11	11	11	10	10	2018
1984	11	11	11	11	10	10	2019
1985	11	11	11	11	10	10	2020
1986	11	11	11	11	10	10	2021
1987	11	11	11	11	10	10	2022
1988	11	11	11	11	10	10	2023
1989	11	11	11	11	10	10	2024
1990	11	11	11	11	10	10	2025
1991	11	11	11	11	10	10	2026
1992	11	11	11	11	10	10	2027
1993	11	11	11	11	10	10	2028
1994	11	11	11	11	10	10	2029
1995	11	11	11	11	10	10	2030

Year	1970		1980		1990		Year
	Level	Est.	Level	Est.	Level	Est.	
1960	11	11	11	11	10	10	1995
1961	11	11	11	11	10	10	1996
1962	11	11	11	11	10	10	1997
1963	11	11	11	11	10	10	1998
1964	11	11	11	11	10	10	1999
1965	11	11	11	11	10	10	2000
1966	11	11	11	11	10	10	2001
1967	11	11	11	11	10	10	2002
1968	11	11	11	11	10	10	2003
1969	11	11	11	11	10	10	2004
1970	11	11	11	11	10	10	2005
1971	11	11	11	11	10	10	2006
1972	11	11	11	11	10	10	2007
1973	11	11	11	11	10	10	2008
1974	11	11	11	11	10	10	2009
1975	11	11	11	11	10	10	2010
1976	11	11	11	11	10	10	2011
1977	11	11	11	11	10	10	2012
1978	11	11	11	11	10	10	2013
1979	11	11	11	11	10	10	2014
1980	11	11	11	11	10	10	2015
1981	11	11	11	11	10	10	2016
1982	11	11	11	11	10	10	2017
1983	11	11	11	11	10	10	2018
1984	11	11	11	11	10	10	2019
1985	11	11	11	11	10	10	2020
1986	11	11	11	11	10	10	2021
1987	11	11	11	11	10	10	2022
1988	11	11	11	11	10	10	2023
1989	11	11	11	11	10	10	2024
1990	11	11	11	11	10	10	2025
1991	11	11	11	11	10	10	2026
1992	11	11	11	11	10	10	2027
1993	11	11	11	11	10	10	2028
1994	11	11	11	11	10	10	2029
1995	11	11	11	11	10	10	2030

$A\frac{1}{2}$  Fan Test (With Back Pressure)

Band Center Freq	n = 2600		3000		3200		3450	
	SPL	Spec Level	SPL	Spec Level	SPL	Spec Level	SPL	Spec Level
100	77	64.5	83	75.5	99	86.5	85	72.5
125	78	63	82	67	84	69	79	64
160	75	59	77	61	79	63	78	62
200	74	57.5	76	59.5	77	60.5	76	59.5
250	85	67.5	78	60.5	79	61.5	81	63.5
320	80	61.5	79	60.5	82	63.5	81	62.5
400	74	54.5	76	56.5	79	59.5	86	66.5
500	73	52	74	53	76	55	79	58
630	71	49	74	52	75	53	77	55
800	72	49	74	51	76	53	79	56
1000	76	52	79	55	80	56	82	58
1250	76	51	80	55	80	55	82	57
1600	73	47	78	52	78	52	79	53
2000	72	45	76	49	77	50	79	52
2500	71	43	73	45	74	46	76	48
3200	68	39	71	42	73	44	74	45
4000	67	37	72	42	74	44	75	45
5000	62	31.5	67.5	37	70	39.5	73	42.5
6300	58	27	62	31	65	34	68	37
8000	55	23.5	60	28.5	62	30.5	64	32.5
10000	51	19	55	23	57	25	60	28
<hr/>								
Overall SPL								
0"	92		97		104		96	
3"	92		97		103		96	
6"	92		97		103		95.5	
8"	93		96		103		96.5	
<hr/>								
Average Overall SPL	92.4		96.8		103.2		96.0	
<hr/>								
Current (amps)	4.2		4.65		4.93		5.3	
Voltage	50.0		60.0		65.5		73.0	
Back Pressure	.38		.45		.49		.54	



STATE OF ILLINOIS DEPARTMENT OF REVENUE

Date	1953		1954		Total
	1953	1954	1953	1954	
10/01	100	100	100	100	400
10/15	100	100	100	100	400
10/30	100	100	100	100	400
11/15	100	100	100	100	400
12/01	100	100	100	100	400
12/15	100	100	100	100	400
12/31	100	100	100	100	400
1953 Total	1000	1000	1000	1000	4000
1954 Total	1000	1000	1000	1000	4000
Grand Total	2000	2000	2000	2000	8000

$A\frac{1}{2}$  Fan Test (With Back Pressure)

Band Center Freq.	n = 3800		4200		4400	
	SPL	Spec Level	SPL	Spec Level	SPL	Spec Level
100	88	75.5	80	67.5		
125	87	72	82	67		
160	79	63	79	63		
200	80	63.5	78	61.5		
250	81	63.5	82	64.5		
320	80	61.5	81	62.5		
400	84	64.5	84	64.5		
500	79	58	83	62		
630	78	56	80	58		
800	80	57	83	60		
1000	83	59	84	60		
1250	84	59	86	61		
1600	81	55	82	56		
2000	80	53	82	55		
2500	78	50	80	52		
3200	75	46	77	48		
4000	77	47	78	48		
5000	76	45.5	78	47.5		
6300	72	41	75	44		
8000	68	36.5	71	39.5		
10000	63	31	65.5	33.5		
<hr/>						
Overall SPL						
0"		97		99		99.5
3"		98		99		99.5
6"		98		100		100
8"		99		100.5		100
<hr/>						
Average Overall SPL		98.0		99.6		99.8
<hr/>						
Current (amps)		5.82		6.38		6.65
Voltage		84.5		95.0		102.0
Back Pressure		.61		.66		.7

Table 1 (continued) (Data from Table 1)

Year	1980		1981		Total
	1980	1981	1980	1981	
1000	100	100	100	100	400
1100	100	100	100	100	400
1200	100	100	100	100	400
1300	100	100	100	100	400
1400	100	100	100	100	400
1500	100	100	100	100	400
1600	100	100	100	100	400
1700	100	100	100	100	400
1800	100	100	100	100	400
1900	100	100	100	100	400
2000	100	100	100	100	400
2100	100	100	100	100	400
2200	100	100	100	100	400
2300	100	100	100	100	400
2400	100	100	100	100	400
2500	100	100	100	100	400
2600	100	100	100	100	400
2700	100	100	100	100	400
2800	100	100	100	100	400
2900	100	100	100	100	400
3000	100	100	100	100	400
3100	100	100	100	100	400
3200	100	100	100	100	400
3300	100	100	100	100	400
3400	100	100	100	100	400
3500	100	100	100	100	400
3600	100	100	100	100	400
3700	100	100	100	100	400
3800	100	100	100	100	400
3900	100	100	100	100	400
4000	100	100	100	100	400
4100	100	100	100	100	400
4200	100	100	100	100	400
4300	100	100	100	100	400
4400	100	100	100	100	400
4500	100	100	100	100	400
4600	100	100	100	100	400
4700	100	100	100	100	400
4800	100	100	100	100	400
4900	100	100	100	100	400
5000	100	100	100	100	400
5100	100	100	100	100	400
5200	100	100	100	100	400
5300	100	100	100	100	400
5400	100	100	100	100	400
5500	100	100	100	100	400
5600	100	100	100	100	400
5700	100	100	100	100	400
5800	100	100	100	100	400
5900	100	100	100	100	400
6000	100	100	100	100	400
6100	100	100	100	100	400
6200	100	100	100	100	400
6300	100	100	100	100	400
6400	100	100	100	100	400
6500	100	100	100	100	400
6600	100	100	100	100	400
6700	100	100	100	100	400
6800	100	100	100	100	400
6900	100	100	100	100	400
7000	100	100	100	100	400
7100	100	100	100	100	400
7200	100	100	100	100	400
7300	100	100	100	100	400
7400	100	100	100	100	400
7500	100	100	100	100	400
7600	100	100	100	100	400
7700	100	100	100	100	400
7800	100	100	100	100	400
7900	100	100	100	100	400
8000	100	100	100	100	400
8100	100	100	100	100	400
8200	100	100	100	100	400
8300	100	100	100	100	400
8400	100	100	100	100	400
8500	100	100	100	100	400
8600	100	100	100	100	400
8700	100	100	100	100	400
8800	100	100	100	100	400
8900	100	100	100	100	400
9000	100	100	100	100	400
9100	100	100	100	100	400
9200	100	100	100	100	400
9300	100	100	100	100	400
9400	100	100	100	100	400
9500	100	100	100	100	400
9600	100	100	100	100	400
9700	100	100	100	100	400
9800	100	100	100	100	400
9900	100	100	100	100	400
10000	100	100	100	100	400

Overall 100%  
 10000  
 10000  
 10000

Overall 100%  
 10000  
 10000  
 10000

9. Effect of Reversing Fan Direction  $A\frac{1}{2}$ ,  $n = 3450$  RPMOctave-Band Analysis

Band Freq Range	Spec Level Corr	Amb	Forward Direction			Back Direction		
			SPL	Corr. for Amb	Spec Level	SPL	Corr for Amb	Spec Level
75 - 150	18.8	55	63	62.5	43.7	62	61	42.2
150 - 300	21.8	55	61.5	61	39.2	60	58.5	36.7
300 - 600	24.8	41	66	66	41.2	65	65	40.2
600 - 1200	27.8	38	60	60	32.2	61.5	61.5	33.7
1200 - 2400	30.8	34	62.5	62.5	31.7	66.5	66.5	35.7
2400 - 4800	33.8	22	59.5	59.5	25.7	58.5	58.5	24.7
4800 - 10 kc	37.2	20	54	54	16.8	52	52	14.8
Overall SPL	0"	82	94			95		
	3"	82	94			95		
	6"	82	95			95		
	8"	82	95			96		
Average Overall SPL		82	94.5			95.2		

Effect of Revealing Tax Direction on the  
 Effect of Revealing Tax Direction on the  
 Effect of Revealing Tax Direction on the

Coffee-Band Analysis

Band Level Range	Band Level	Band Level	Band Level	Band Level	Band Level	Band Level	Band Level
150 - 175	162.5	15.8	22	63	65.2	43.7	65
150 - 200	175	21.5	25	61.5	61	39.5	60
200 - 250	225	24.8	41	68	66	41.5	65
250 - 300	275	27.8	38	60	60	35.2	61.5
300 - 350	325	30.8	36	62.5	62.5	31.7	66.5
350 - 400	375	33.8	35	65.2	64.5	28.7	67.2
400 - 450	425	37.2	32	67	64	25.8	65

Overall SPI	6°	8°	9°	10°
Overall SPI	6°	8°	9°	10°

Average Overall SPI 88.2

C. CALCULATIONS1. Adapter Design

Circular to Square Cross-Section (Equal Areas)

$$\frac{\pi D^2}{4} = S^2$$

$$D = 21.1875" \quad S = 18.76"$$

D = Diameter in inches

S = Side of Square Section  
in inches2. Design of Exponential Horn

$$A = A_0 e^{mx}$$

x = Longitudinal Distance  
from throat

$$\frac{\text{Equiv. Circ. Circum.} \geq 1}{\lambda}$$

m = Flaring Constant

$$m = \frac{2\pi f_0}{c}$$

$$\lambda = \frac{c}{f_0}$$

 $f_0$  = Cutoff FrequencyLowest fan speed is  
1000 RPM

$$f_0 = \frac{\text{RPM}_{\text{fan}} \times N}{60}$$

7 Blades

N = Fan Blades (7)

$$f_0 \approx 100 \text{ cps}$$

c = Speed of Sound in Air =  
1128 fps

$$\lambda = 11.28 \text{ ft.}$$

 $A_0$  = Throat Area

A = Area at Station x

Equivalent Circular Circumference (C) = 11.28 Ft. = 125.36 In.

$$A_{\text{mouth}} = \frac{(C^2)}{4\pi} = 1451.0 \text{ In.}^2 \text{ for Square Cross-Section}$$

$$S_{\text{mouth}} = 38.1 \text{ In.}$$

$$mc = 2\pi f_0$$

$$A_0 = 356.0 \text{ In.}^2$$

$$m = \frac{2\pi \times 100}{1128} = 0.557$$

$$S_0 = 18.76 \text{ In.}$$

$$\frac{1451.0}{356.0} = e^{0.557 X} = 4.07$$

$$X = 2.52 \text{ Ft.}$$

(Length of Horn)

CALCULATION

1. Motor Input

Output of Motor (horsepower) (hp) = 100

$$P = \frac{W}{t} = \frac{100 \times 746}{1} = 74,600 \text{ W}$$

D = Diameter in inches  
L = Length of shaft in inches

2. Torque of Motor

n = Rotational speed from motor

w = Weight constant

$$T = \frac{W}{n}$$

T = Torque

$$T = \frac{W}{n} = \frac{100 \times 746}{1000} = 74.6 \text{ ft-lb}$$

n = Rev/min (rpm)

v = Speed of shaft in ft/min

D = Diameter in inches

$$v = \frac{\pi D n}{12}$$

Input Power (hp) = 100

Output Power (hp) = 100

$$P = 100 \text{ hp}$$

$$P = 11.8 \text{ ft-lb}$$

Shaft diameter (D) = 1.125 in = 1.125 in

$$D = \sqrt[3]{\frac{16 T}{\pi S}} = \sqrt[3]{\frac{16 \times 74.6}{\pi \times 10,000}} = 1.125 \text{ in}$$

$$S = 10,000 \text{ psi}$$

$$T = 74.6 \text{ ft-lb}$$

$$D = 1.125 \text{ in}$$

$$D = 1.125 \text{ in}$$

(Length of shaft)

2. Design of Exponential Horn (continued)

$$A = A_0 e^{mx}$$

$$A_0 = 356.0 \text{ in}^2$$

$$m = .557$$

$x(\text{ft})$	$A_0$	$e^{mx}$	$A_x$	$S_x(\text{in})$
0	356	1	356	18.76 (throat)
0.5	356	1.322	471	21.72
1	356	1.746	621	24.94
1.5	356	2.310	822	28.65
2	356	3.05	1087	32.98
2.52	356	4.07	1451	38.10 (mouth)



(continued) TABLE 1 - STATISTICAL DATA

$$A = A_{0} e^{-\lambda t} \quad \ln A = \ln A_{0} - \lambda t$$

(min)	$A$	$\ln A$	$A$	$\ln A$
0	100	4.605	100	4.605
0.2	92.1	4.523	92.1	4.523
1	84.2	4.437	84.2	4.437
2	76.3	4.351	76.3	4.351
3	68.4	4.265	68.4	4.265
4	60.5	4.179	60.5	4.179
5	52.6	4.093	52.6	4.093
6	44.7	4.007	44.7	4.007

3. Horn Check

$$I = \frac{\bar{p}^2}{\rho c}$$

$c$  = Speed Sound in air, cm/sec

$\rho$  = Density of air, dynes/cm<sup>3</sup>

$\bar{p}$  = RMS Pressure, dynes/cm<sup>2</sup>

$$IL = 10 \log_{10} \frac{I}{10^{-16}}$$

$$SPL = 10 \log_{10} \frac{\bar{p}^2}{(0.0002)^2}$$

$$\Delta IL = IL_x - IL_{throat} = 10 \log_{10} \frac{\bar{p}_x^2}{\bar{p}_{throat}^2}$$

$$\Delta SPL = SPL_x - SPL_{throat} = 10 \log_{10} \frac{\bar{p}_x^2}{\bar{p}_{throat}^2} =$$

$$= \Delta SPL = \Delta IL$$

$$I = \frac{\pi}{A \times 930}$$

$\pi$  = Sound Power in watts

$A$  = Area in square feet

$$\Delta IL = 10 \log_{10} \frac{\frac{\pi}{A_x \times 930}}{\frac{\pi}{A_{throat} \times 930}} = 10 \log_{10} \frac{A_{throat}}{A_x}$$

$$\frac{A_{throat}}{A_x} = \frac{1}{e^{mx}} = e^{-mx}$$

$x$  = Axial distance in horn from throat, feet.

$$\Delta IL = 10 \log_{10}(e^{-mx}) = -10 mx \log_{10} e =$$

$$(-4.36) (0.557) (x) = \underline{-2.43x = \Delta IL = \Delta SPL}$$

This gives the theoretical variation of change in sound-pressure level from the horn throat with axial horn distance.

$\rho = \text{fluid density in air, kg/m}^3$   
 $\rho = \text{density of air, kg/m}^3$   
 $\bar{u} = \text{avg velocity, cm/sec}$

$$I = \frac{1}{2} \rho \bar{u}^2$$

$$I_1 = 10 \text{ kg/m}^2 \cdot \frac{1}{2} \rho \bar{u}_1^2$$

$$I_2 = 10 \text{ kg/m}^2 \cdot \frac{1}{2} \rho \bar{u}_2^2$$

$$I_1 = I_2 \quad \rho \bar{u}_1^2 = \rho \bar{u}_2^2 \quad \bar{u}_1 = \bar{u}_2$$

$$I_1 = I_2 \quad \rho \bar{u}_1^2 = \rho \bar{u}_2^2 \quad \bar{u}_1 = \bar{u}_2$$

$$I_1 = I_2$$

$\rho = \text{fluid density in water}$   
 $\rho = \text{density of water}$

$$I = \frac{1}{2} \rho \bar{u}^2$$

$$I_1 = 10 \text{ kg/m}^2 \cdot \frac{1}{2} \rho \bar{u}_1^2$$

$$I_2 = 10 \text{ kg/m}^2 \cdot \frac{1}{2} \rho \bar{u}_2^2$$

$$I_1 = I_2 \quad \rho \bar{u}_1^2 = \rho \bar{u}_2^2 \quad \bar{u}_1 = \bar{u}_2$$

$$I_1 = I_2 \quad \rho \bar{u}_1^2 = \rho \bar{u}_2^2 \quad \bar{u}_1 = \bar{u}_2$$

This shows the theoretical velocity of flow in  
 equal-pressure level from the flow chart with  
 equal flow distance.

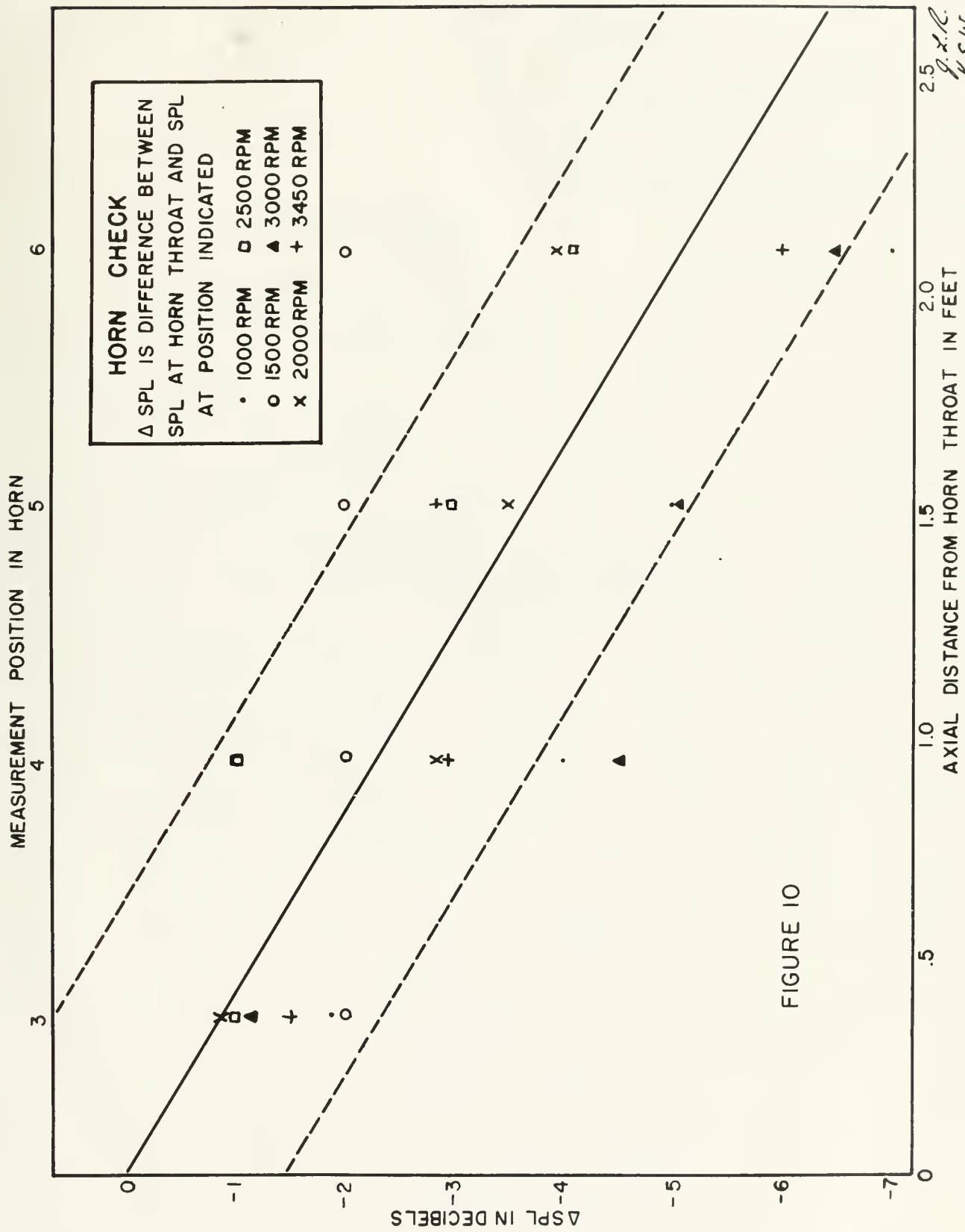


FIGURE 10

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4. Conversion from SPL to PL in the Measuring Duct

SPL = Sound-pressure level in  
decibels

PL = Power level in decibels

I = Intensity, watts/cm<sup>2</sup>

$\pi$  = Power, watts

A = Duct cross-section area in cm<sup>2</sup>

$$\text{SPL} = \text{IL} = 10 \log_{10} \frac{I}{10^{-16}}$$

$$\text{PL} = 10 \log_{10} \frac{\pi}{0.9 \times 10^{-13}}$$

$$\pi = IA$$

$$\text{PL} = 10 \log_{10} \frac{IA}{10^{-16}}$$

$$I = 10^{-16} \text{ anti-log}_{10} \frac{\text{SPL}}{10}$$

$$\text{PL} = 10 \log_{10} \frac{(10^{-16})(\text{anti-log}_{10} \frac{\text{SPL}}{10})(A)}{0.9 \times 10^{-13}}$$

$$\text{PL} = \text{SPL} + 10 \log_{10} A - 29.55$$

$$\text{Duct Diameter} = 21 \frac{1}{8}''$$

$$A = 2.25 \times 10^3 \text{ cm}^2$$

$$\text{PL} = \text{SPL} + 4.0 \text{ decibels}$$

$10 = 100 \times 10^{-2}$   
 $12 = 100 \times 10^{-2}$   
 $1 = 100 \times 10^{-2}$   
 $1 = 100 \times 10^{-2}$   
 $1 = 100 \times 10^{-2}$

$$10 = 100 \times 10^{-2} = 10 \times 10^{-1}$$

$$12 = 100 \times 10^{-2} = 12 \times 10^{-1}$$

$$1 = 100 \times 10^{-2}$$

$$1 = 100 \times 10^{-2} = 1 \times 10^{-1}$$

$$1 = 100 \times 10^{-2} = 1 \times 10^{-1}$$

$$10 = 100 \times 10^{-2} = 10 \times 10^{-1}$$

$$12 = 100 \times 10^{-2} = 12 \times 10^{-1}$$

$$1 = 100 \times 10^{-2}$$

$$1 = 100 \times 10^{-2}$$

$$12 = 100 \times 10^{-2} = 12 \times 10^{-1}$$

5. Power Calculations

a. Resistance measurement from blocked rotor test

$$I = 0.4 \text{ amps}$$

$$V = 0.7 \text{ volts}$$

$$r_2 + r_s = \frac{0.7}{0.4} = 1.75 \text{ ohms} = R_a + s =$$

Resistance of armature plus series field

b. HP calculation - Assume motor windage losses and stray losses = 0

$$HP = \frac{1}{746} (IV - I^2 R_a + s)$$

n	I	V	VI	$I^2 R_{a+s}$	HP calc	$HP \sim n^2$	$HP \sim n^2$
800	2.40	14.2	34	10.10	0.030	---	---
900	2.42	15.1	36.6	10.25	0.035	---	---
1000	2.43	16.9	41.0	10.33	0.041	---	---
1100	2.44	18.2	44.5	10.40	0.046	---	---
1200	2.55	19.5	49.7	11.38	0.051	---	---
1300	2.60	21.0	54.5	11.81	0.057	---	---
1500	2.78	24.3	67.5	13.02	0.073	0.073	0.027
1700	2.90	27.9	80.9	14.70	0.089	0.092	0.033
2000	3.05	33.3	101.5	16.30	0.114	0.128	0.046
2300	3.40	39.9	135.7	20.20	0.155	0.170	0.062
2500	3.55	45.9	162.8	22.00	0.189	0.200	0.073
2600	3.76	48.8	183.4	24.10	0.224	0.216	0.079
3000	4.04	55.0	222.0	28.40	0.259	0.289	0.105
3200	4.25	60.0	255.0	31.60	0.299	0.329	0.120
3450	4.60	70.0	322.0	37.00	0.382	0.382	0.140
3800	5.00	78.0	390.0	43.80	0.465	0.464	---
4200	5.60	90.0	504.0	54.90	0.600	0.566	---
4600	6.10	104.0	635.0	65.10	0.762	0.680	---

$$HP A \frac{1}{2} = \frac{0.4}{1.1} \times 0.382 = 0.140$$

at rated speed and no back pressure



Linear Calculations

Horizontal measurements from disused river bank

$$I = 0.4 \text{ m} \quad V = 0.7 \text{ m/s}$$

$$v = \frac{I}{T} = \frac{0.4}{1.75} = 0.228 \text{ m/s}$$

maintainance of constant plus various fields

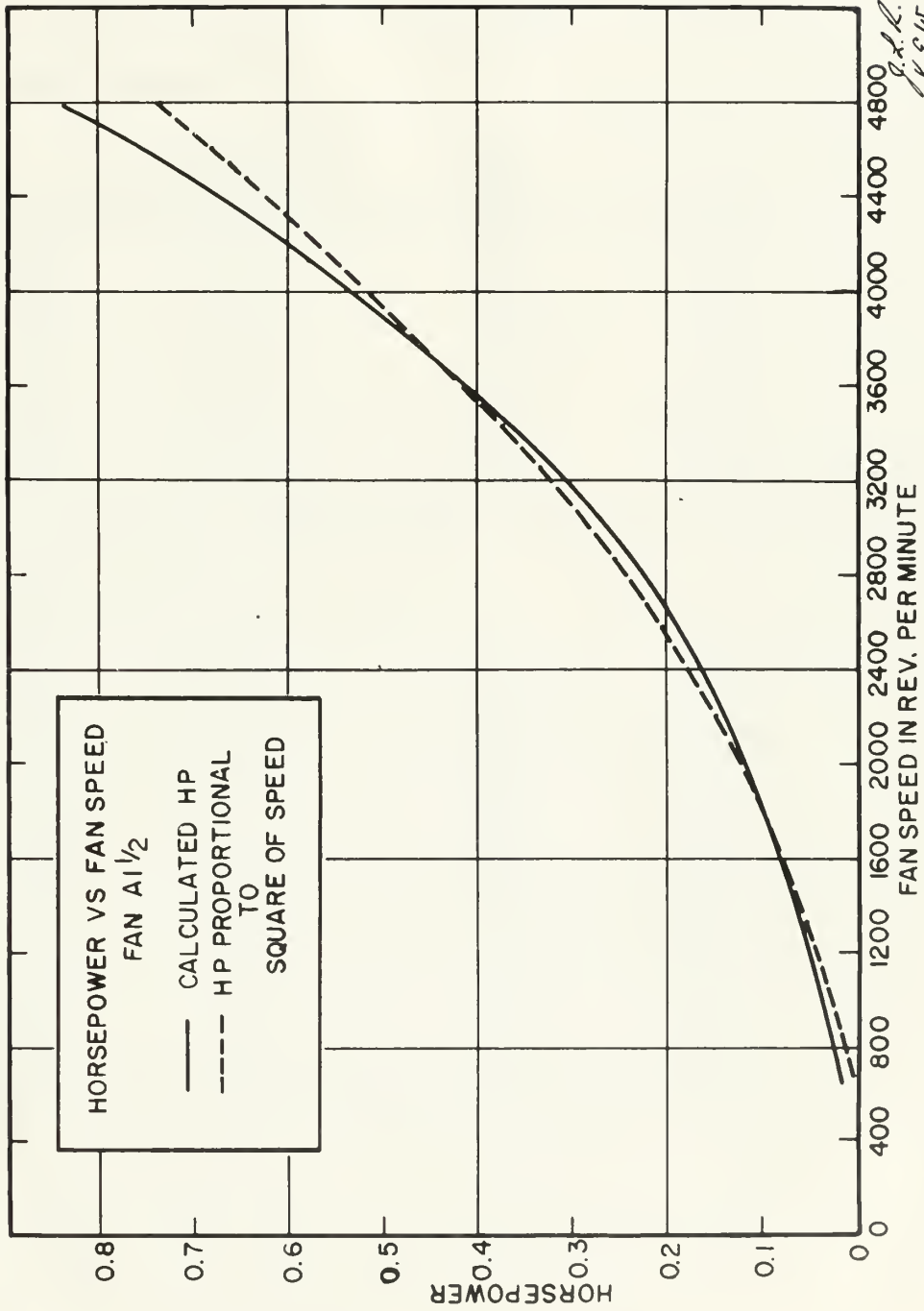
IV calculation - assume water velocity is zero

$$IV = \frac{I}{T} = \frac{0.4}{1.75} = 0.228$$

$\frac{1}{T}$	$\frac{1}{T}$	$\frac{1}{T}$	$\frac{1}{T}$	$\frac{1}{T}$	$\frac{1}{T}$	$\frac{1}{T}$	$\frac{1}{T}$
---	---	0.000	10.10	0.10	24	5.18	0.00
---	---	0.002	10.10	0.002	24	5.18	0.00
---	---	0.004	10.10	0.004	24	5.18	0.00
---	---	0.006	10.10	0.006	24	5.18	0.00
---	---	0.008	10.10	0.008	24	5.18	0.00
---	---	0.010	10.10	0.010	24	5.18	0.00
---	---	0.012	10.10	0.012	24	5.18	0.00
---	---	0.014	10.10	0.014	24	5.18	0.00
---	---	0.016	10.10	0.016	24	5.18	0.00
---	---	0.018	10.10	0.018	24	5.18	0.00
---	---	0.020	10.10	0.020	24	5.18	0.00
---	---	0.022	10.10	0.022	24	5.18	0.00
---	---	0.024	10.10	0.024	24	5.18	0.00
---	---	0.026	10.10	0.026	24	5.18	0.00
---	---	0.028	10.10	0.028	24	5.18	0.00
---	---	0.030	10.10	0.030	24	5.18	0.00
---	---	0.032	10.10	0.032	24	5.18	0.00
---	---	0.034	10.10	0.034	24	5.18	0.00
---	---	0.036	10.10	0.036	24	5.18	0.00
---	---	0.038	10.10	0.038	24	5.18	0.00
---	---	0.040	10.10	0.040	24	5.18	0.00
---	---	0.042	10.10	0.042	24	5.18	0.00
---	---	0.044	10.10	0.044	24	5.18	0.00
---	---	0.046	10.10	0.046	24	5.18	0.00
---	---	0.048	10.10	0.048	24	5.18	0.00
---	---	0.050	10.10	0.050	24	5.18	0.00

$$\frac{1}{T} = \frac{I}{T} = \frac{0.4}{1.75} = 0.228$$

to be used and of data given



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FIGURE 11



6. Calculated Curves Based on

$$PL = 121.5 + 3.0 \log_{10} \frac{HP/Blade}{200} - \frac{34800}{n}$$

$A\frac{1}{2}$  (No Back Pressure)

n	HP	$3.0 \log \frac{HP/Blade}{200}$	$\frac{34800}{n}$	PL
2000	.047	-13.4	17.4	91.3
2300	.062	-13.1	15.2	93.7
2600	.080	-12.7	13.4	95.9
3000	.105	-12.4	11.6	98.0
3200	.120	-12.2	10.9	98.9
3450	.140	-12.0	10.1	99.9

$A1\frac{1}{2}$  (No Back Pressure)

2000	.128	-12.1	17.4	92.5
2300	.170	-11.7	15.2	95.1
2600	.216	-11.4	13.4	97.2
3000	.289	-11.1	11.6	99.3
3200	.329	-10.9	10.9	100.2
3450	.382	-10.7	10.1	101.2
3800	.464	-10.4	9.2	102.4
4200	.566	-10.2	8.3	103.5
4600	.621	- 9.9	7.6	104.5

2. Calculated curves based on

$$P_1 = 121.2 + 2.0 \log \frac{WV/\Delta t}{h} - \frac{3400}{h}$$

$\frac{1}{2}$  (No Back Pressure)

$P_1$	$\frac{WV/\Delta t}{h}$	$\frac{WV/\Delta t}{h}$	$P_1$	$\frac{WV/\Delta t}{h}$
91.7	17.4	-12.4	1000	.047
93.7	12.2	-12.1	1500	.062
92.9	13.4	-12.7	2000	.080
98.0	11.6	-12.4	3000	.102
98.9	10.9	-12.5	3500	.120
99.9	10.1	-12.6	3750	.140

$\frac{1}{2}$  (No Back Pressure)

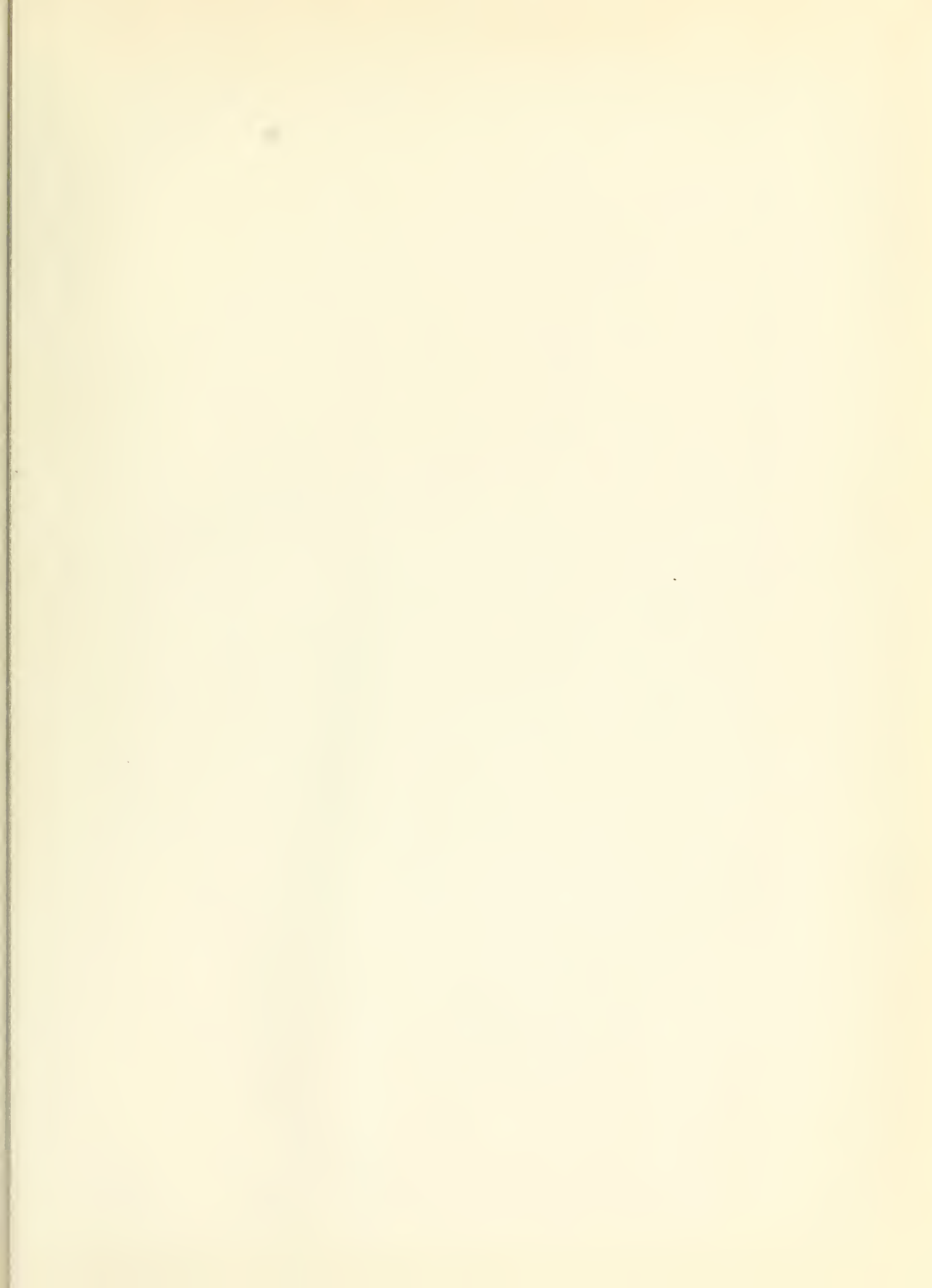
104.2	7.6	- 9.2	4000	.161
103.5	8.2	-10.2	4500	.182
102.4	9.2	-10.4	5000	.204
103.5	10.1	-10.7	3450	.382
100.9	10.9	-10.9	3500	.382
99.3	11.6	-11.1	3000	.289
97.5	13.4	-11.4	2000	.212
92.1	12.2	-11.1	1500	.170
92.2	17.4	-12.1	1000	.138

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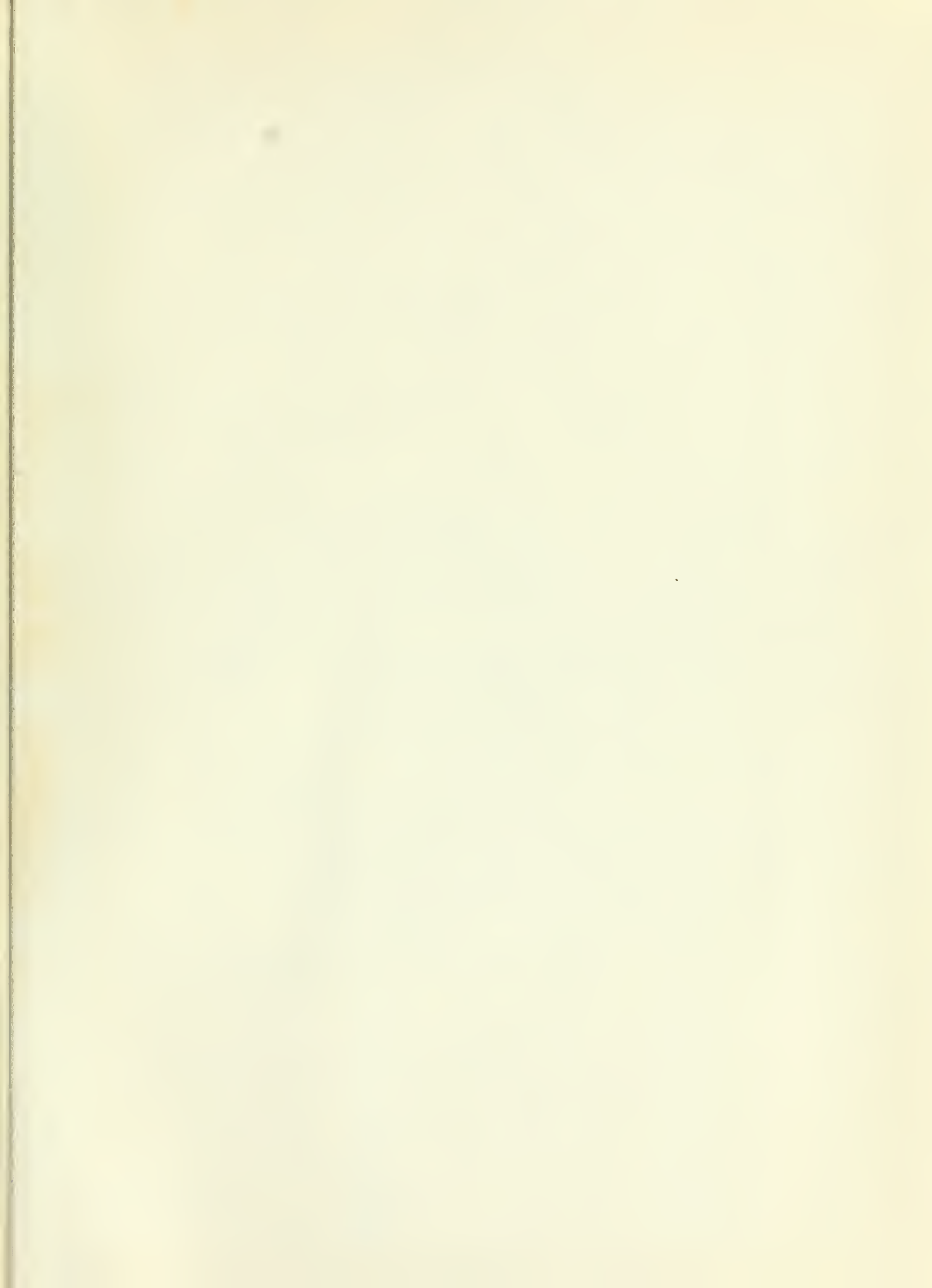
TRANSLATIONS

- 1. On the Theory of the Motion of a Particle  
 by L. I. Senner and L. W. Hudson  
 Jour. Acoust. Soc. Am., Vol. 19, No. 2, March 1947  
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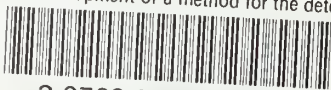
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