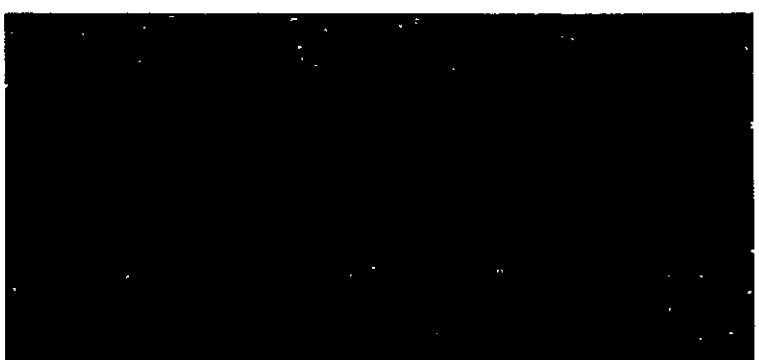(NASA-CR-155152)   A RESEARCH PROGRAM TO
REDUCE INTERIOR NOISE IN GENERAL AVIATION
AIRPLANES. DESIGN OF AN ACOUSTIC PANEL TEST
FACILITY   Progress Report (Kansas Univ.
Center for Research, Inc.)   102 p

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THE UNIVERSITY OF KANSAS CENTER FOR RESEARCH, INC.

2291 Irving Hill Drive—Campus West
Lawrence, Kansas 66045

Progress Report

for

A RESEARCH PROGRAM TO REDUCE INTERIOR
NOISE IN GENERAL AVIATION AIRPLANES
KU-FRL-317-3
NASA Grant NSG 1301

DESIGN OF AN ACOUSTIC PANEL
TEST FACILITY

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Lawrence, Kansas

August 1977

ACKNOWLEDGEMENTS

SUMMARY

An acoustic panel test facility was designed and constructed to
determine the sound transmission loss characteristics of various panels
and panel treatments. The experimental testing is one of the major
project objectives outlined in Chapter 1. The other objectives brought
out in this chapter include: comparing experimental results with
analytical methods, providing a data base of panel and panel treatment
attenuation characteristics and possibly extending present prediction
methods or developing new ones.

Chapter 2 is concerned with the design and construction phase as
well as the cost of this facility. Some of the problems encountered
with the construction are mentioned there. A discussion of the
pressurization system and a section on the electronic equipment used
for this project is also included.

The reliability of this facility and examples of data gathered using
this system are reported in Chapter 3. The test results are compared
to pertinent acoustical theories for panel behavior and the minor
anomalies in the data are also discussed. A new method for predicting
panel behavior in the stiffness region is also presented.

This facility consists of a brick wall (6' x 6' x 1') with a nine-
foot-long square tube (28" x 28") which rests on a 16-foot-long steel
table. The clamped panels tested using this facility are 20" x 20" with
a maximum thickness of 1" (the exposed area is 18" x 18").

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LIST OF SYMBOLS

Symbol	Definition	Usual Dimension
b	Panel length	m
c	Speed of sound	m/sec
c_L	Speed of compressional waves	m/sec
$D = \dfrac{Eh^3}{12(1 - \nu^2)}$	Flexural rigidity	Nm
E	Young's modulus	N/m^2
f	Frequency	Hz
$f_{1,1}$	Fundamental resonance frequency	Hz
g	Gravitational acceleration	m/sec^2
h	Panel thickness	m
K	Correction factor	dB
$\overline{m}$	Mass of the panel per unit area	kg/m^2
NR	Noise Reduction	dB
TL	Transmission Loss	dB

Greek Symbols

Symbol	Definition	Usual Dimension
γ	Specific weight of the material	N/m^3
λ	Frequency parameter	
ν	Poisson's ratio	
ρ_a	Density of air	kg/m^3
ρ_m	Density of the panel material	kg/m^3
ρ_s	Panel surface density	kg/m^2
ω	Frequency	rad/sec

LIST OF ABBREVIATIONS

FRL   Flight Research Laboratory

KU   University of Kansas

NASA   National Aeronautics and Space Administration

CHAPTER 1

INTRODUCTION

This report describes the design, construction and calibration of
the acoustic panel test facility located at the Flight Research
Laboratory (FRL) in Raymond Nichols Hall on the campus of the University
of Kansas (KU). This facility (shown in Figure 1.1), a plane wave tube,
is used to experimentally determine the sound transmission loss
characteristics of various structural panels and panel treatments.

Members of the Flight Research Laboratory conferred with officials
from the National Aeronautics and Space Administration (NASA) and two
major general aviation manufacturers during the six months preceding
the extension of NASA grant number NSG 1301. The conversations focused
on the broad problems related to interior noise reduction. These
meetings produced two major conclusions. First, in-cabin noise levels
are high, despite the use of acoustical treatments, and secondly, methods
available for predicting and comparing the acoustic behavior of bare
and treated panels are quite limited.

Relatively simple methods have been developed to predict sound
transmission losses through infinite panels with evenly distributed mass
and stiffness. Examples of these methods are found in References 1, 2,
and 3. Even the characteristics of simple laminated panels can be pre-
dicted fairly accurately. Methods to predict the response of more
complicated structures, like honeycomb materials or composite structures
of thin skins with stiffeners, yield less than satisfactory results
(References 1, 4, and 5).

Many of the acoustic materials used by the general aviation industry
are tested by the manufacturer under specific or ideal conditions (which

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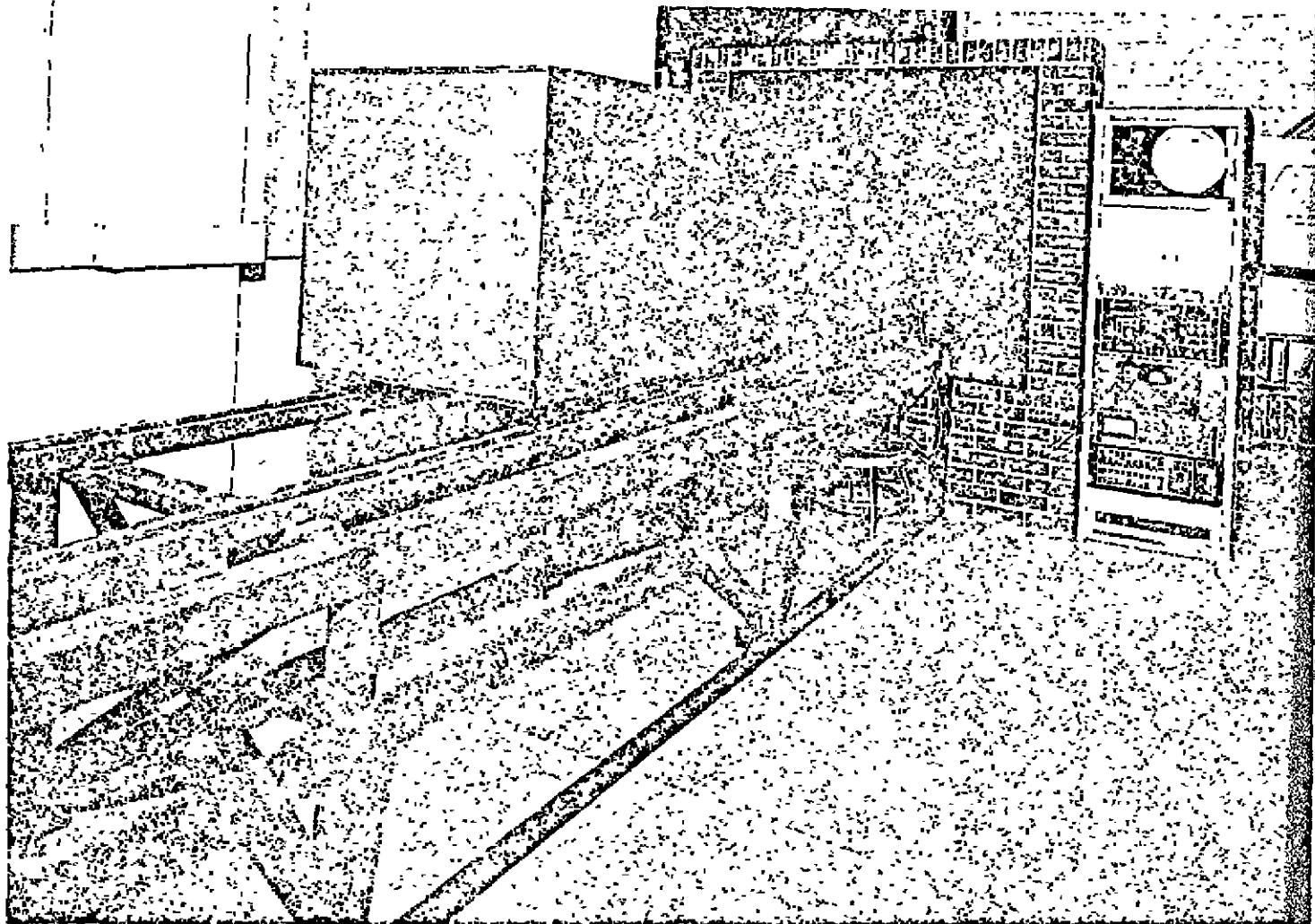
Figure 1.1 The Plane Wave Tube Test Facility

are not always comparable). Their specifications form a limited base for any product decision or improvement.

Basically there are three methods for determining the sound transmission loss (TL) characteristics of complicated built-up finite panels: (1) a purely analytical approach, (2) an empirical method in which existing theories are verified or expanded by experimental results, and (3) an extensive test program theoretically unsupported. Since the analytical approach may be very time consuming and result in only approximate or limited solutions, an empirical approach would be more beneficial.

As a result of the various meetings and discussions, the KU-FRL noise group submitted a proposal to NASA which contained the following four major program objectives:

1. To determine the sound transmission loss characteristics of various structural panels and panel treatments (experimentally).

2. To compare test results with predictions from pertinent analytical methods.

3. To provide a systematic collection of panel and panel treatment sound attenuation characteristics, based on both experimental and analytical considerations.

4. To use these results to extend or develop prediction methods.

Laboratory measurements of transmission loss can normally be made using either a reverberant chamber or an acoustic tube. The reverberant chamber provides random incident noise which is statistically uniform over the test specimen. In the acoustic tube, the sound is propagated normal to the surface of the specimen (or at some predetermined angle). Since it is intended to explore the influence of angle of sound incidence

on selected panels, the acoustic tube was the practical selection.

Financial limitation also made this choice more attractive.

CHAPTER 2

TEST APPARATUS

This chapter contains a description of the plane wave tube test
facility and its associated electronic equipment. A discussion of
the pressurization system and the factors influencing the design of
this facility are presented. Also reported is the construction phase
and its resulting costs.

2.1 Description of the Plane Wave Tube

The plane wave tube used in this project is similar to the one
designed by Beranek for his early work with sound control in airplanes
(Reference 6). A sketch of the tube is shown in Figures 2.1 and 2.2.
A pair of small microphones is used to measure the sound level on each
side of a panel clamped between the source and receiving chambers.

The source chamber consists of four main items: the speakers,
the main plate, the speaker box, and the brick wall. Nine Altec model
405-G speakers are mounted on a one-half inch steel plate which is
securely attached to a brick wall by twelve three-quarter inch bolts.
The speakers are surrounded by a massive steel and reinforced concrete
collar and are backed by a heavy steel box filled with fiberglass to
reduce sound transmission to the rear. The principal reason for using
such heavy materials is to assure that noise received by the microphone,
in the receiving chamber, passes through the test specimen only. Any
signal trying to reach the receiving microphone by means of a flanking
path will be attenuated to such a level that it will not interfere with
the signal passing through the specimen.

The receiving chamber consists of a tube eighteen inches square
inside a twenty-seven inch square outer tube. The space between the

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Section A-A
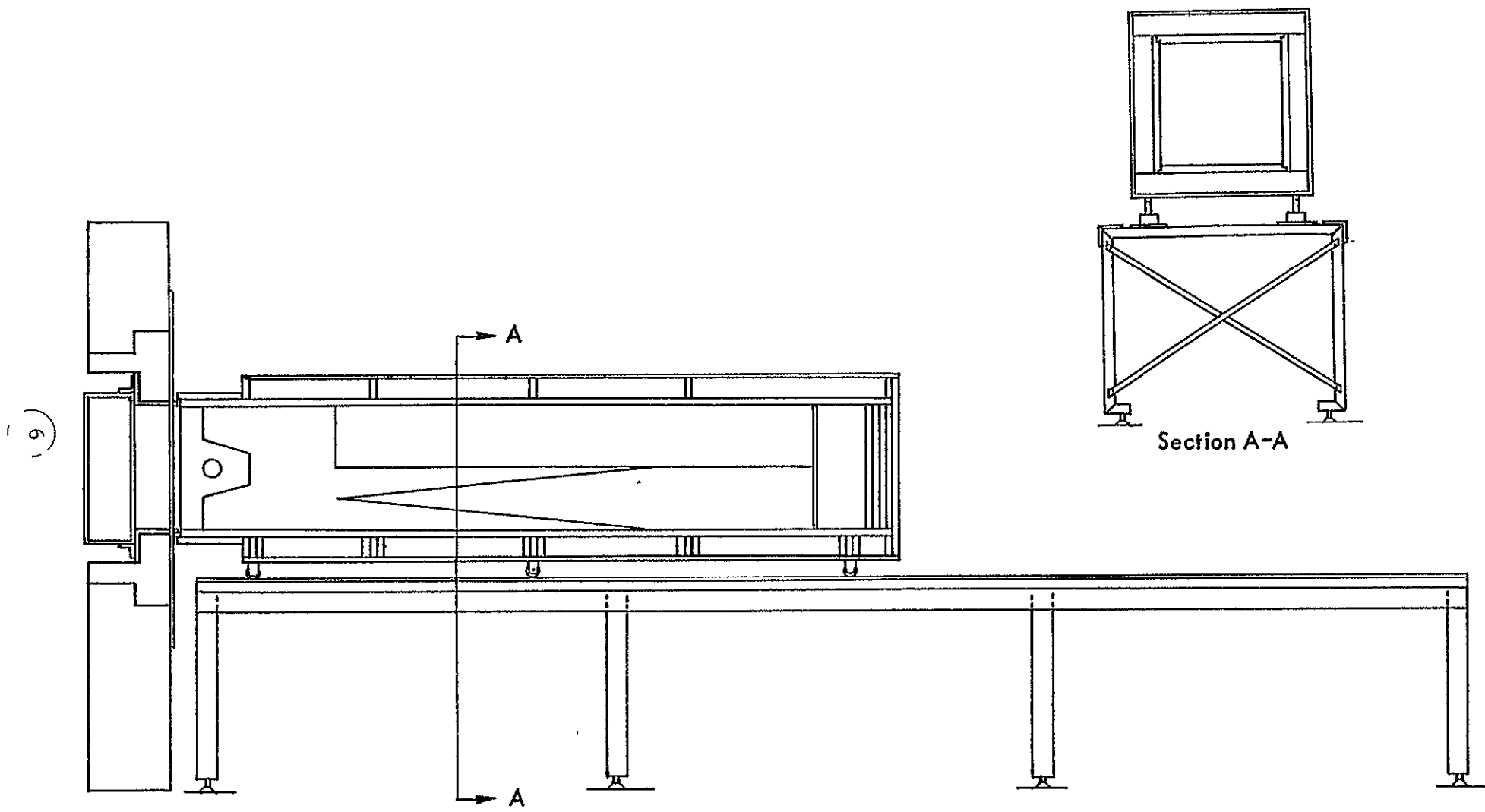
Figure 2.1. Plane Wave Tube.

Brick Wall
Concrete and Steel Collar
Absorptive Material in Speaker Box
Baffle Plate
9-Altec Loudspeakers

Test Specimen
Absorbing Termination Material

Absorptive Material between Baffle Plate and Test Specimen
1" Particle Board

Receiver Microphone
Source Microphone

Speaker Input
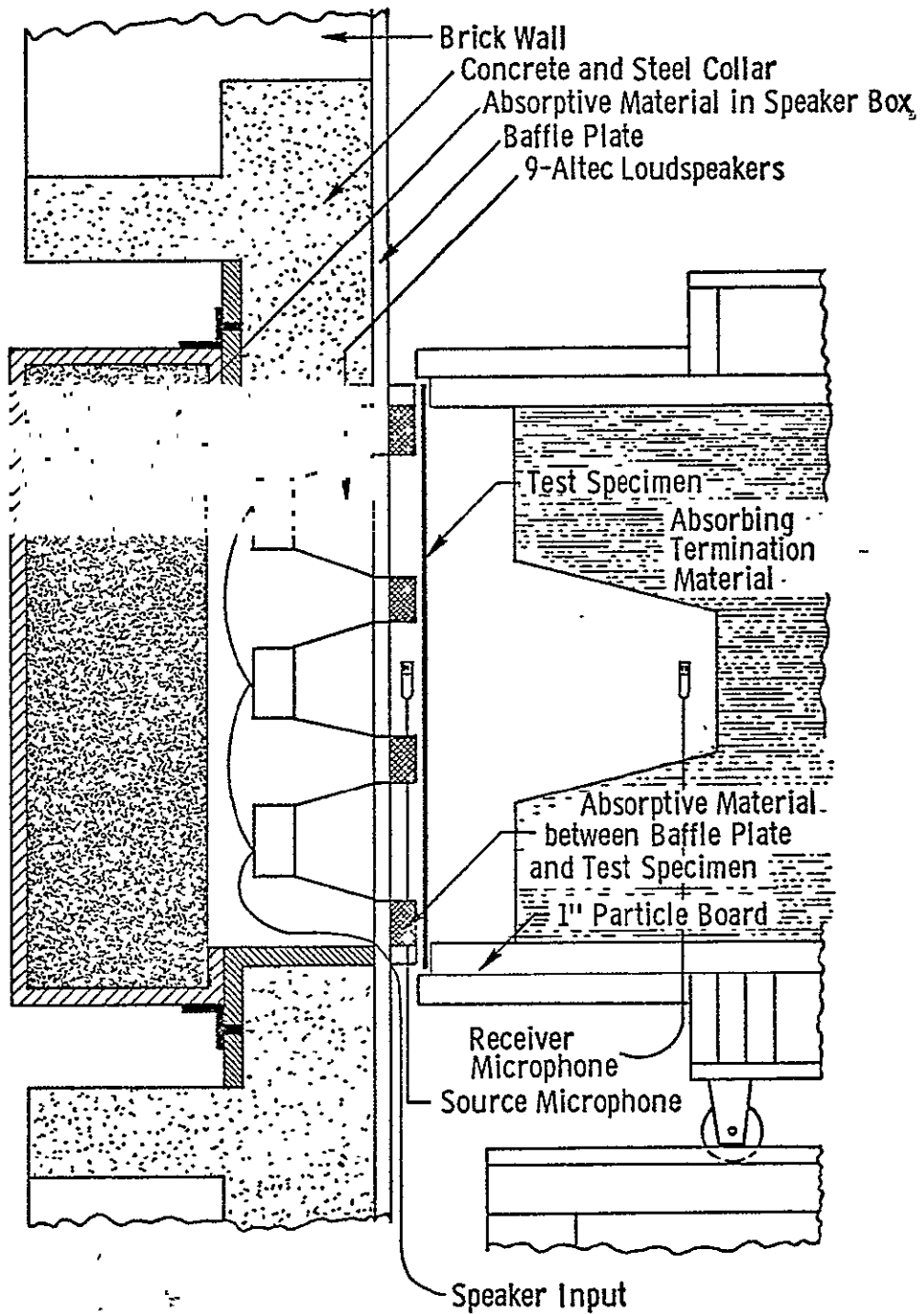
Figure .2.2. Detail Drawing of Test Specimen Installation.

tubes is filled with fiberglass to reduce unwanted radiation. The inside tube contains eighteen inches of loosely packed foam followed by four highly absorbent fiberglass wedges. The wedges are followed by eight inches of cotton and four inches of fiberglass.

The overall length of the wedges is sixty inches, which includes a rectangular base twenty-four inches long. The wedges are nine inches square and made from semi-rigid fiberglass to help preserve their shape. The density of the fiberglass used in the wedges is three lbs/ft^3. The wedges are positioned in the tube with their blades alternated to present a maximum absorbent area to the sound.

The loose foam in front of the wedges absorbs high frequencies in the neighborhood of the receiving microphone, and reduces transverse standing waves. The cotton and fiberglass packed behind the wedges help absorb lower frequencies.

The tube is mounted on six wheels and rests on a sixteen foot long steel table. The movable tube not only allows for easy changing of test specimens but also facilitates the insertion of a special test section. The special test section allows slanted and curved specimens to be tested in the plane wave tube.*

Figures 2.3 through 2.6 show various sections of the plane wave tube testing facility.

Table 2.1 lists the principal drawings used in the construction of the plane wave tube test facility. These drawings are on file at the Flight Research Laboratory of the University of Kansas.

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*The special test section will be discussed in a future report.

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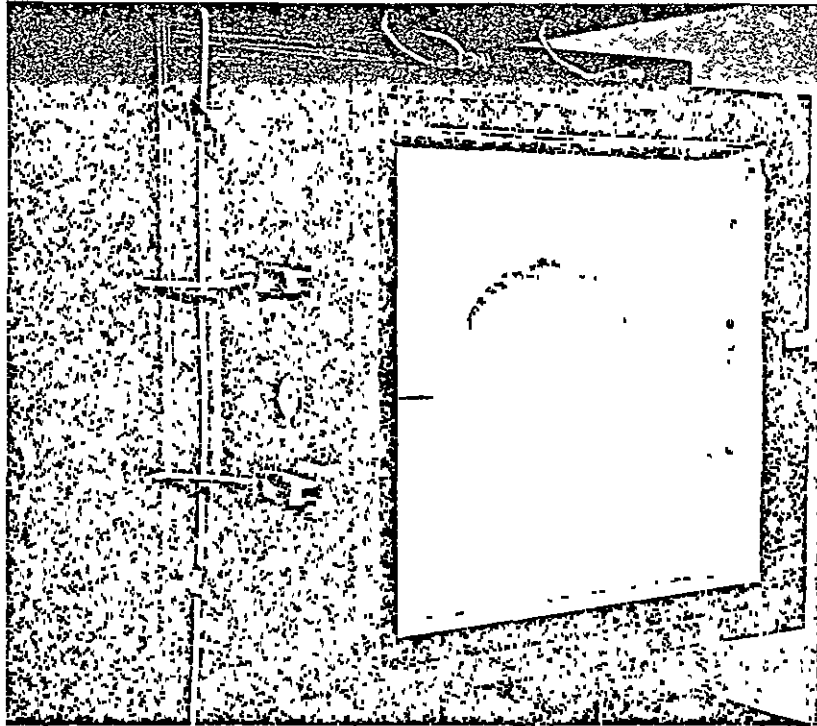
Figure 2.3 Front Section of the Plane Wave Tube Detailing the
Location of the Receiver Microphone, the Temperature
Gauge, and the Clamps

Figure 2.4 Front Section of Plane Wave Tube with Test Specimen
in Position
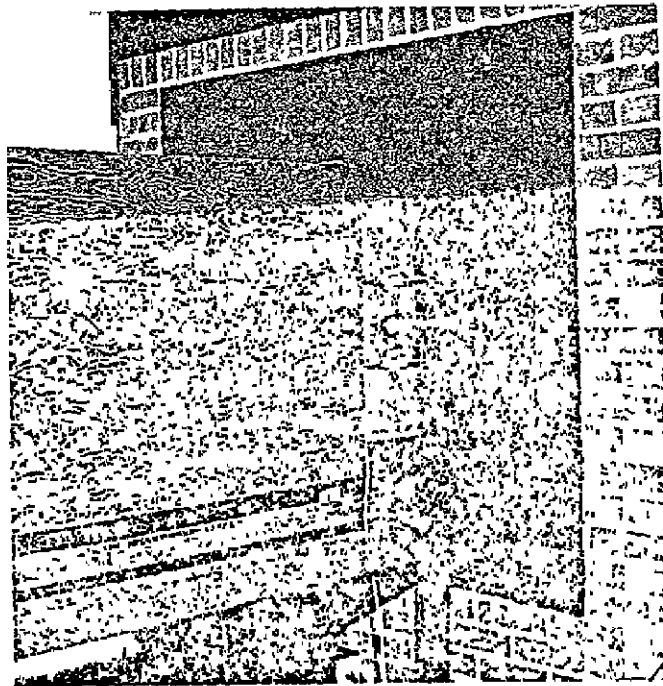
Figure 2.5 Plane Wave Tube Clamped to Wall in the Testing
Configuration
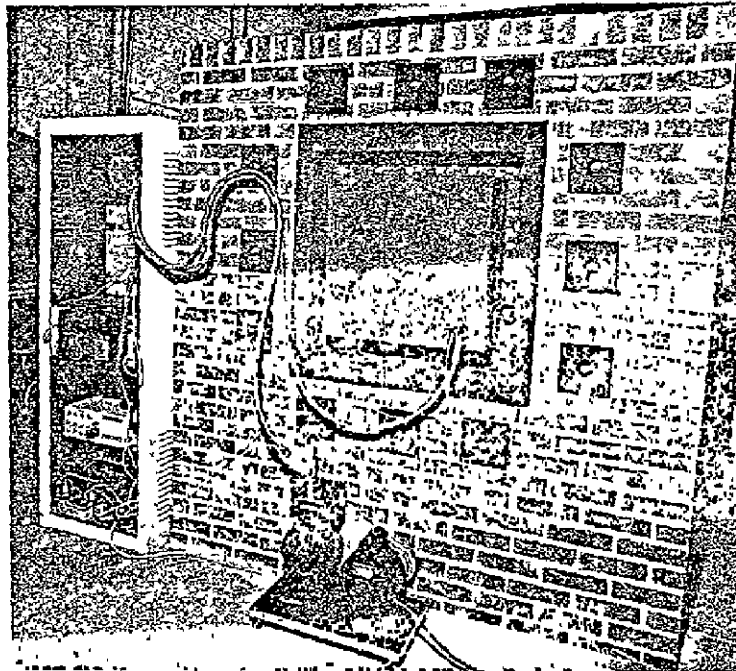
Figure 2.6 Rear Surface of the Brick Wall Showing How the
Speaker Box is Attached to the Collar, and Portions
of the Pressure System

Table 2.1 Principal Drawings of the Plane Wave Tube
1. Overall side view of test facility.
2. Detail close-up of wall and front end of tube.
3. Detail drawing of main plate.
4. Detail drawing of speaker box.
5. Detail drawing of concrete collar.

2.2 Design Considerations

Using Beranek's early design of a plane wave tube as a model, a testing facility was designed to fill the needs of the KU-FRL acoustic testing program. The present facility allows two types of panels to be tested: panels perpendicular to the source chamber (a) with a pressure differential, and (b) without a pressure differential across the panels. This facility also allows for the insertion of a special test section. When this test section is built, it will fit between the source and receiving chambers. This test section will permit testing of flat and curved panels at various angles of incidence to the source chamber.

To test panels using the special test section, the plane wave tube had to be designed such that the test section could be easily inserted and would be compatible with the existing facility. For this reason the table was designed with a rail system which facilitates easy move-ment of the tube. The table length was increased to sixteen feet to accommodate the test section when in use. A simple and effective clamping system was designed to permit the operator of the system rapid access to the specimen and to be compatible with and without the

test section in place. Figure 2.7 shows an example of what the test section might look like when in place with the plane wave tube.

During the preliminary design phase, questions were raised as to the amount of noise that would be radiated into the lab by the test apparatus. It was extremely difficult to predict what the noise level would be inside the laboratory, but the likelihood of undesirable levels was expected to be high. Consequently, certain portions of the design were modified to help insure a quieter testing environment for the operators of this facility. The inner tube was designed with thicker and more rigid walls. The space between the inner tube and the outside shell was filled with four inches of fiberglass.

The capabilities of the plane wave tube were expanded with the addition of a pressure system. This system would allow a pressure differential to be applied across the panel being tested. The system was designed to simulate the pressurization conditions found in some airplanes. The static pressure of the source chamber would be reduced while maintaining the receiver chamber at atmospheric pressure.

2.3 Costs

A major consideration for the construction of an acoustic testing facility at KU was cost. To obtain the necessary funding from NASA for acoustic research, it was necessary that the plane wave tube be inexpensive and provide reliable data. The reliability of this facility is discussed in Chapter 3. A breakdown of the total cost shown below in Table 2.2, indicates that the construction costs represent approximately 10% of the money spent on the entire test facility. Construction costs were slightly more than the $2000 budgeted for this activity.

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Special Test Section

Highly Absorptive Foam Wedges

Test Specimens
at Various Angles
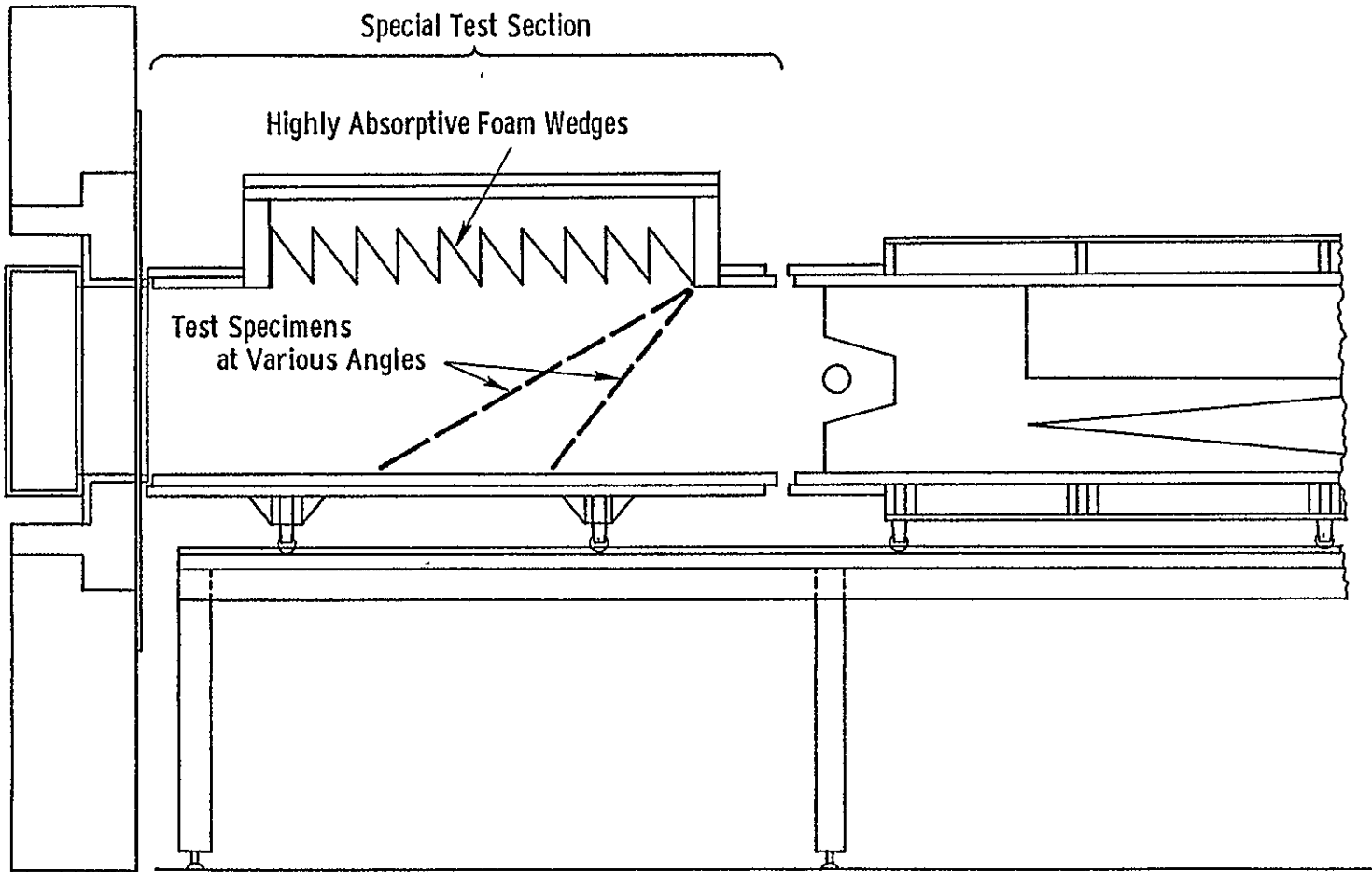
Figure 2.7.   Example of a Test Section under Study.

Table 2.2 Cost of the KU-FRL Acoustic Panel Test Facility

Construction Costs

Tube

Receiving chamber	356.00		
Acoustic materials	136.18		
Fixtures	62.79		
Miscellaneous expenses	93.38		
		657.36	

Wall and Table

Brick wall	475.00		
Steel	440.73		
Concrete	15.92		
Special labor	70.00		
Miscellaneous expenses	319.55		
		1,321.20	

Pressure System

Differential Pressure Gauge	178.27		
Tubing, gaskets and valves	50.14		
Miscellaneous expenses	68.24		
		296.65	
Total Construction Costs			2,275.20

Electronic Equipment

Pistonphone	623.00		
Microphones	862.00		
Microphone preamplifiers	1,062.00		
Microphone power supply	499.00		
Speakers	154.44		
Real time analyzer	9,950.00		
Tape recorder	3,353.67		
X-Y recorder	2,295.20		
Equalizer	219.00		
Power amplifier	499.00		
Miscellaneous equipment	55.00		
		19,572.31	
Total Electronic Equipment Costs			19,572.31

Total Cost for Facility			21,847.51

2.4 Construction Phase

This phase of the project started on the 10th of March 1977 and took three months to complete. A timeline showing the major milestones of this phase is illustrated in Figure 2.8.

In early March the blueprints of the receiving chamber were given to Crestmark Woods. During the remainder of that month, the following items were accomplished:

1. Mr. R. T. Bruce, a local mason, constructed the lower section of the wall.

2. Mr. D. Nelson, the Aerospace Engineering Department machinist, built the steel portion of the collar and constructed the form required for pouring the concrete collar.

3. Mr. Nelson started construction of the speaker box and the table that the tube rests on.

By the middle of April, the construction phase reached its peak and the facility started taking shape. During this period the following items were accomplished:

1. The steel and reinforced concrete collar was poured.

2. The collar was placed on the lower section of the wall.

3. Mr. Bruce built the upper section of the wall.

4. The steel table was brought into the lab and assembled.

5. The tube was moved into the lab.

During the remainder of the month, finishing work such as painting the table, varnishing the tube, and other small jobs were done.

During the last six weeks of construction several minor problems arose. The first problem concerned the one-half inch thick steel main plate (42 x 42 inches). The plate had to have nine four-inch

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	Oct.	1976 Nov.	Dec.	Jan.	Feb.	Mar.	1977 Apr.	May	June	July	Aug.

Preliminary Design Phase

Plane Wave Tube Drawing Finalized

Construction Begun — (10)

Concrete Collar Completed — (16)

Tube Moved Into Lab — (20)

Wall Completed — (23)

Tube Put on Table — (1)

Finishing Work (Painting, etc.)

Scheduled Completion (FRL) — (1)

Main Plate Attached to Wall — (7)

Construction Completed — (14)

Calibration Begun — (15)

Calibration completed (Tube Fully Operational) — (15)

Report on Design Project Due — (30)

Figure 2.8. Timeline of Major Project Milestones.

diameter holes drilled in it. The use of a cutting torch was ruled out for fear it would warp the plate. To cut these holes according to the design, it was decided to use four-inch diameter metal hole saws. Since this type of saw was not designed to cut one-half inch steel and was not commonly stocked by area merchants, a major time delay in the project resulted when several saws were broken and replacements had to be ordered. The other problem encountered concerned the pressure system. During the initial checkout of the pressure system several major leaks were discovered. The largest leak occurred between the main plate and the wall. This leak resulted because it was assumed that "flat plates" are flat (which is not true). Once this fact had been correctly established, immediate changes were planned and shortly there-after implemented. These changes resulted in a significant improvement, but still did not satisfy the 6 psi pressure differential that was required. After several sealants were tried, a silicon based bathtub sealant was found which cleared up the problem.

In early June the main plate was finished and attached to the wall. Finishing work and work on the pressure system continued. On the 15th of June the construction phase ended and preliminary calibration began.

Figures 2.9 through 2.16 show the plane wave tube in various stages of construction.

2.5 Pressure System

To determine what effects the pressurization system of an airplane has on the sound transmission characteristics of a panel, the capabilities of the plane wave tube were expanded to allow for this type of testing. The minor modifications made to the tube consisted of:
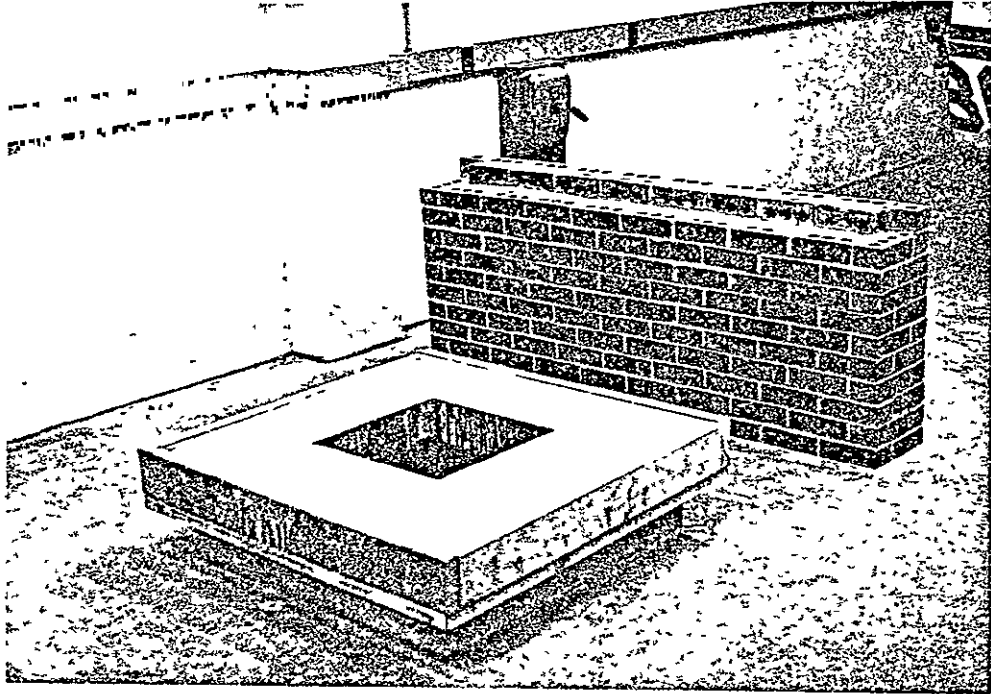
Figure 2.9   Concrete Collar and the Lower Section of the Wall
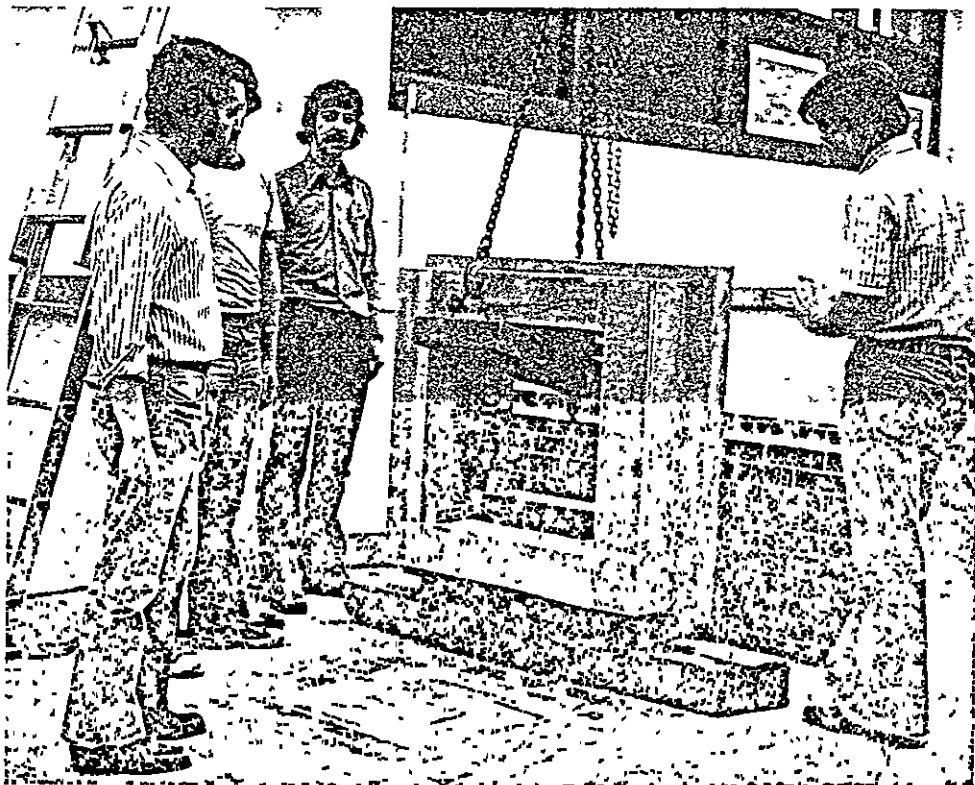
Figure 2.10   Concrete Collar is Readied for Placement on the
Lower Section of the Wall
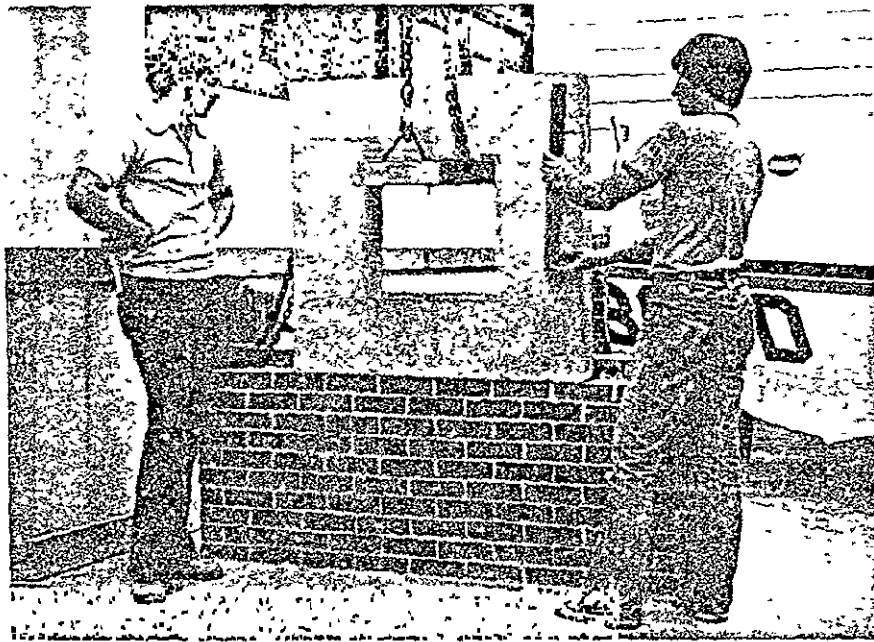
Figure 2.11 Collar Alignment Checked
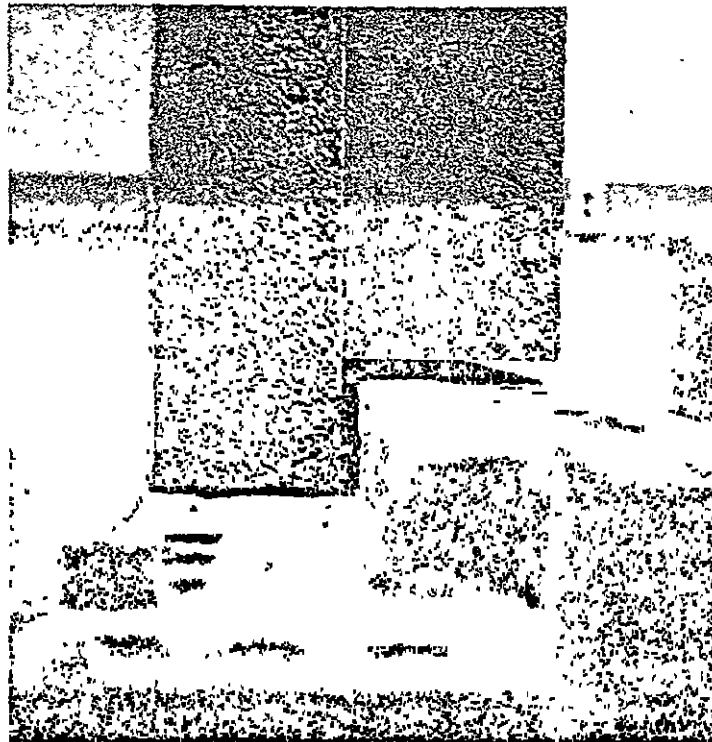
Figure 2.12 Joint Between Collar and Wall
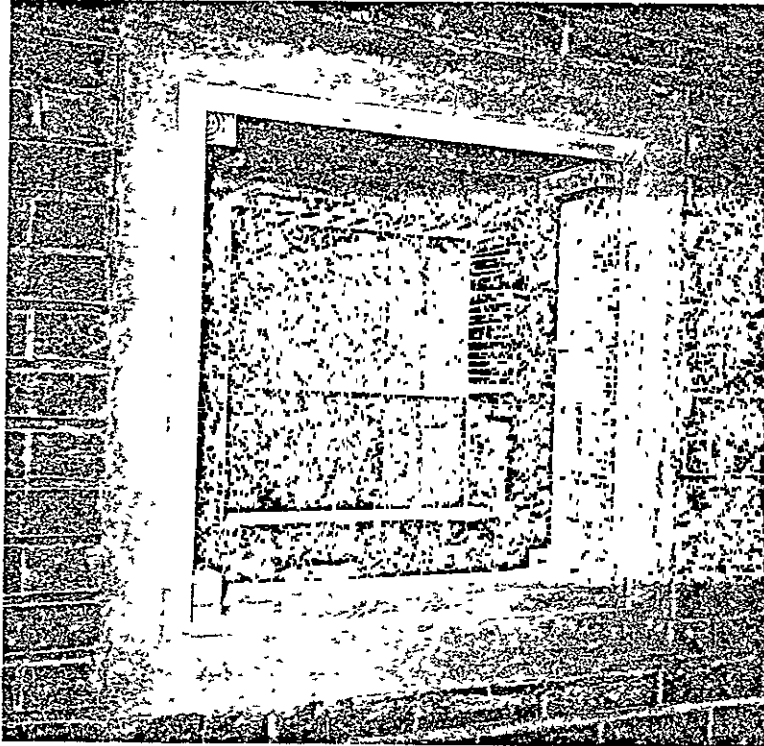
Figure 2.13 Backside of Collar Where Speaker Box Attaches
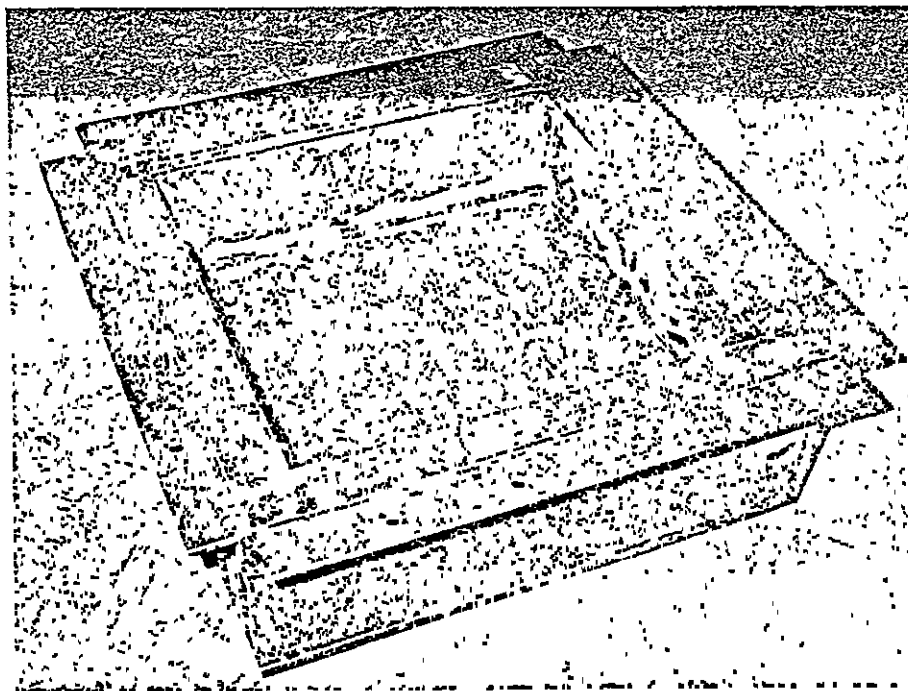
Figure 2.14 Speaker Box
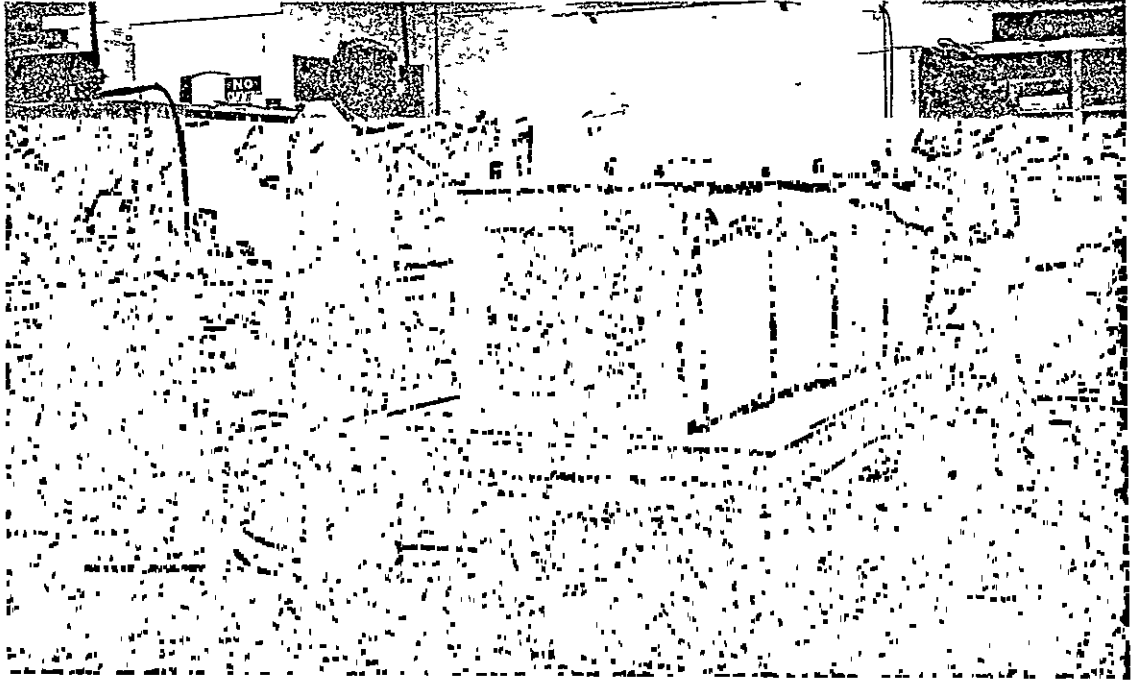
Figure 2.15 Plane Wave Tube Before Outer Skin Attached
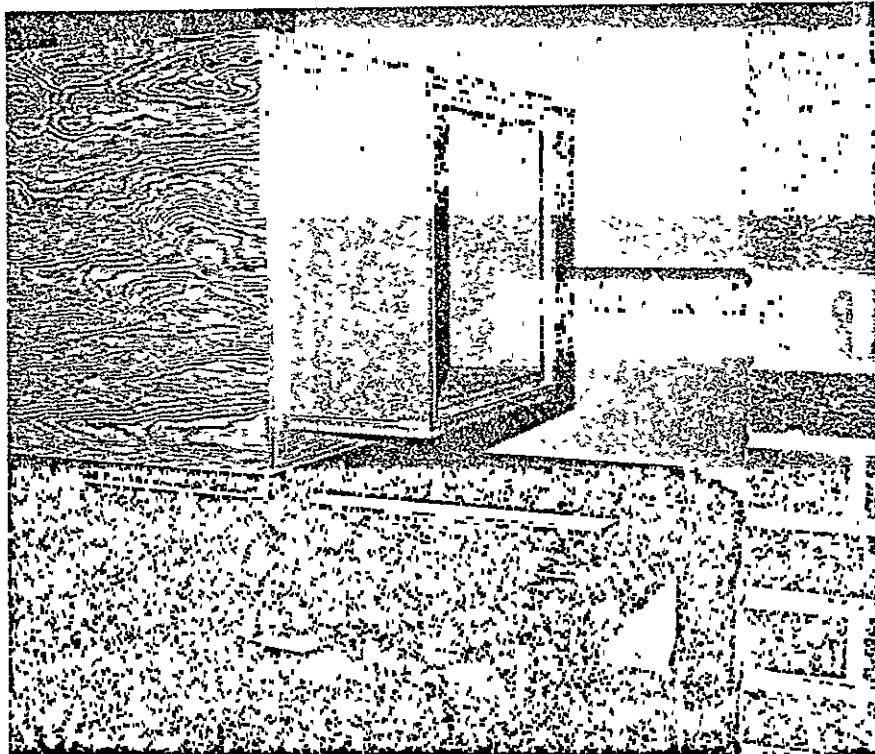
Figure 2.16. Plane Wave Tube on Table

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1. Drilling a hole in the back side of the speaker box to allow the pressure to be reduced behind the speakers;

2. Drilling a small hole in the main plate which would equalize the pressure in front of the speakers as the pressure in the speaker box was decreased;

3. Placing a gasket between the speaker box and the concrete collar;

4. Placing a gasket on the main plate where the panel being tested is sandwiched between the source and receiving chambers;

5. Using a silicon sealer to seal inside the collar, where the main plate comes in contact with the collar;

Additions to the plane wave tube included a vacuum pump, a 0-20 psi differential pressure gauge, and the associated valves and tubing necessary to make the system work. A schematic of this system is illustrated in Figure 2.17.

Originally it was planned to reduce the static pressure in the source chamber in 2 psi increments up to a maximum pressure differential of 6 psi across the panel. During early testing of the pressure system it was found that when thin unstiffened aluminum and steel panels were subjected to the maximum pressure differential, the panels were severely damaged. Therefore, if meaningful trends are to be established, it is recommended that thin unstiffened panels will have to be tested using smaller increments of pressure up to a lower maximum pressure differential. Increments of 0.5 psi are recommended for this class of panels up to a maximum pressure differential of 3-4 psi, depending upon the type of panel being tested.
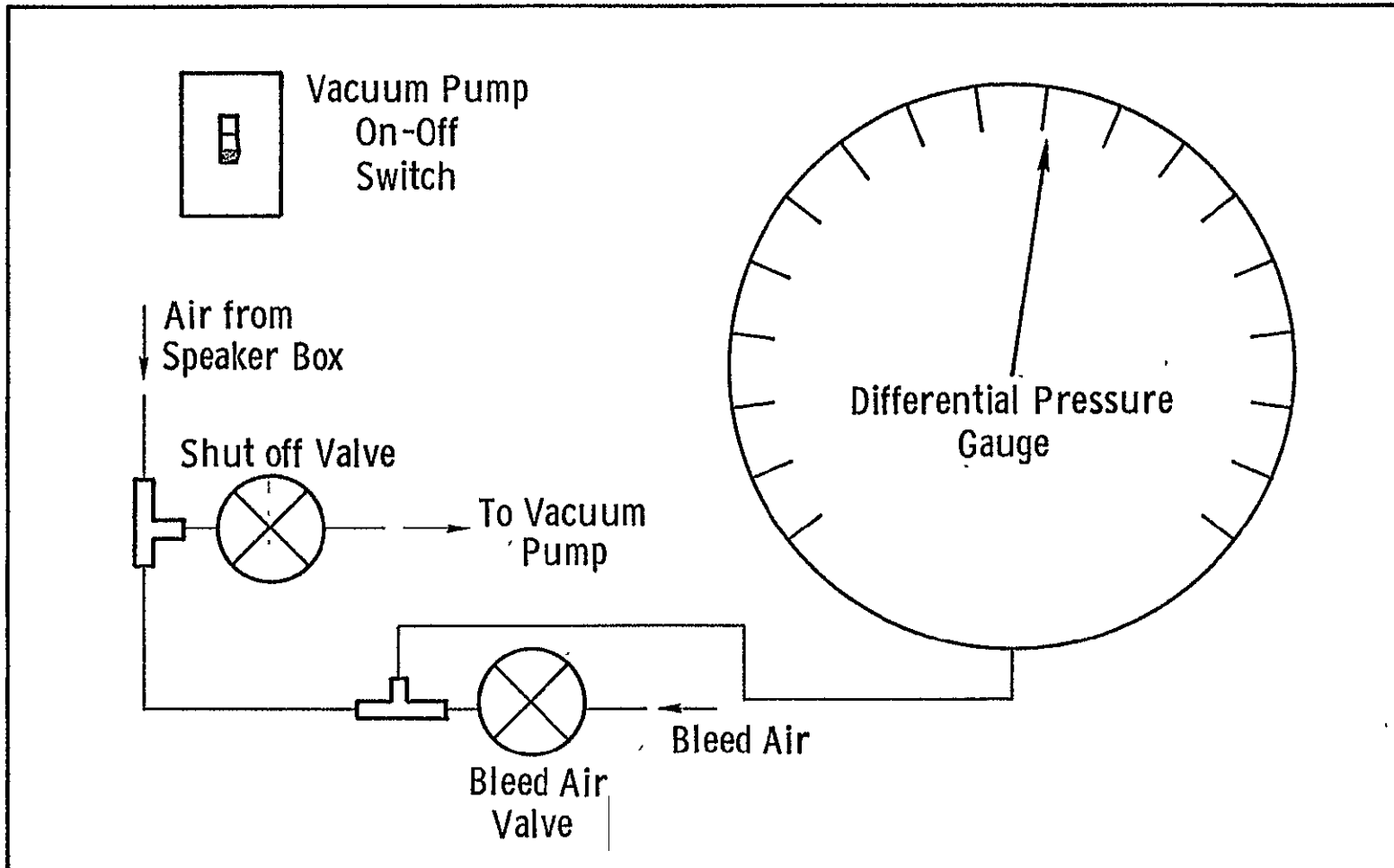
Figure 2.17. Pressure Systems for the Plane Wave Tube.

2.6 Associated Electronic Equipment

The electronic equipment being used in this program can be separated into three main groups: noise generation, noise measurement and noise analysis. A schematic of this system is illustrated in Figure 2.18.

The noise generation section consists of a noise source whose output is fed into an equalizer. The equalizer is used to correct frequency response deficiencies in the Altec speakers. This enhanced output is amplified and is directed to a 3 by 3 array of Altec Speakers.

The panel being tested has a microphone on each side. The source microphone measures the sound generated by the speakers as well as sound being reflected by the panel. The receiver microphone measures the sound that passes through the panel only. The output of these micro- phones is either recorded on the Nagra tape recorder for future reference or fed directly into the SD (Spectral Dynamics) 335 real time analyzer.

The output of the microphone is analyzed in one of two ways, depending on the noise source being used. When a pure tone is swept over a selected frequency range, the analyzer stores the peak signal it receives through each of its 500 filters. When either white noise or a tape recording of actual aircraft noise is used as the source, the analyzer averages the signal received through each of its 500 filters. The number of averages taken is controlled by the operator. The analyzed signal is then plotted on a HP (Hewlett-Packard) 7045 X-Y Recorder.

Figure 2.19 shows the associated electronic equipment that is used with the plane wave tube.

Noise Generation   Noise Measurement   Noise Analysis

A. Altec 405-8G Loudspeakers

B. Crown D-150 Power Amplifier

C. TAPCO 2200 Equalizer

D. Noise Source
   i.) General Radio 1390-A
       Random Noise Generator
   ii.) Tape Recording of Actual
       Aircraft Noise
   iii.) Spectral Dynamics Model
       SD 104-5 Sweep Oscillator

E. B & K 4136 Microphones with
   2618 Preamps

F. B & K 2804 Microphone Power
   Supply

G. Nagra SJS Tape Recorder

H. Spectral Dynamics Model SD335
   Real Time Analyzer

I. HP 7045-A X-Y Recorder

J. HP 9825-A Computer

Figure 2.18.   General Arrangement of Electronic Equipment.
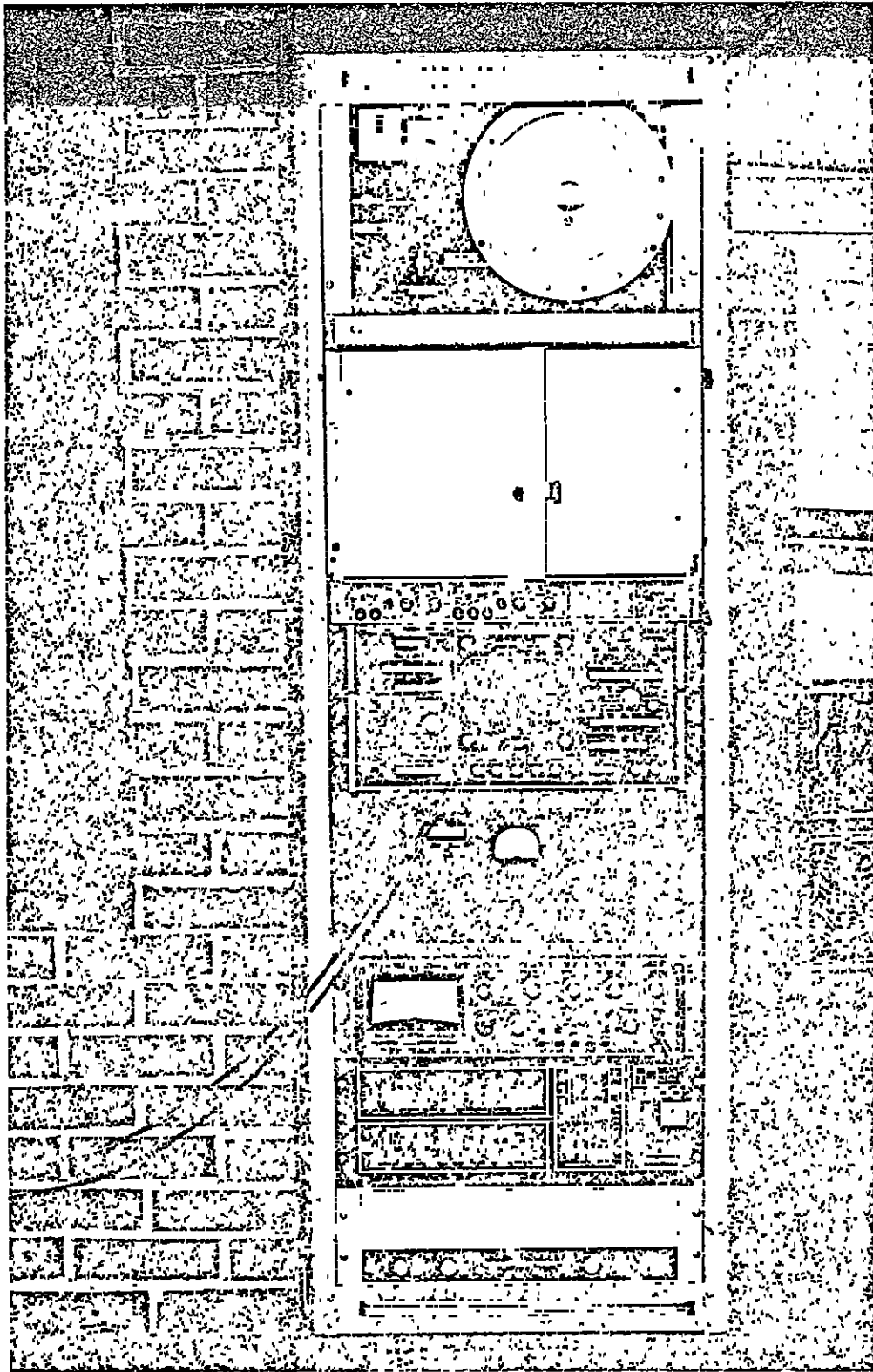
Figure 2.19   Electronic Equipment Associated with the Plane Wave Tube

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CHAPTER 3

CALIBRATION OF THE PLANE WAVE TUBE

This chapter describes the procedures that were used to optimize the acoustic materials in front and behind the speaker array. The results of this optimization are illustrated by graphical comparisons of the power output of the nine speakers. The experimental test results of four test panels are reported and compared to current panel behavior theories. A new method for predicting panel response in the stiffness region is also presented.

3.1 Optimization of Absorptive Material

3.1.1 Between the Speakers and Test Specimen

During the initial checkout of the plane wave tube, lateral standing waves were found between the speakers and the test specimen. Since it was desired to have a uniform sound field, an experimental test program was initiated to minimize these standing waves. Several combinations of fiberglass and foam were tested. A summary of the combinations is listed below.

1. 1" thick fiberglass with no holes cut out for speakers.

2. 1" thick fiberglass with holes cut out for speakers.

3. 1" thick foam with no holes cut out for speakers.

4. 1" thick foam with holes cut out for speakers.

5. 1/2" thick foam with no holes cutout for speakers laminated to a 1/2" thick piece of foam with holes cut out for speakers.

6. 1/2" thick foam with no holes cut out for speakers laminated to a 1/4" thick piece of foam with holes cut out for speakers.

7. 1/4" thick foam with no holes cut out for speakers laminated to a 1/2" thick piece of foam with holes cut out for speakers.

The standing waves were almost completely eliminated when a layer of 1/2" foam with holes cut out for the speakers was laminated to a 1/4" piece of foam with no holes. Although the 1" thick foam did a slightly better job, the 3/4" foam (1/4" no holes laminated to 1/2" with holes) was chosen to assure that an excited panel (with a pressure differential applied) would not come in contact and thus be damped by the foam. The effects of using foam is illustrated by comparing Figures 3.1 and 3.2*.

3.1.2 Behind the Speaker Array

A test was devised to determine whether the performance of the speakers was effected by the air space behind them. This test consisted of encircling the speaker magnets with various thicknesses of fiberglass. Thicknesses of 1, 2, and 4 inches were tested. These tests indicated that speaker response, in the lower frequency range, was slightly improved when 1" thick fiberglass was used. The speaker response deteriorated when greater thicknesses were tested.

3.2 Frequency Response of the Speakers

One of the more important aspects of the plane wave tube is the behavior of the speaker array. It is desirable for all speakers to produce (1) an identical, and (2) a flat spectrum of sound. The microphone on the source side is centered in front of the middle speaker. To determine the uniformity of the speakers, the frequency response of each one was measured and subtracted from the output of the center one. The results of this test are illustrated in Figures 3.3 through 3.10 (original speaker data on file at FRL).

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*The speakers have been sequentially numbered for easy reference, starting in the upper left corner and moving left to right, row by row (as viewed from the receiving chamber).

Sound Pressure Level ~ dB

130

120

110

100

90

80

70

2   3   4 5 6 7 8 9   2   ·3   4 5 6 7 8 9   2   3   4 5
            100   1000
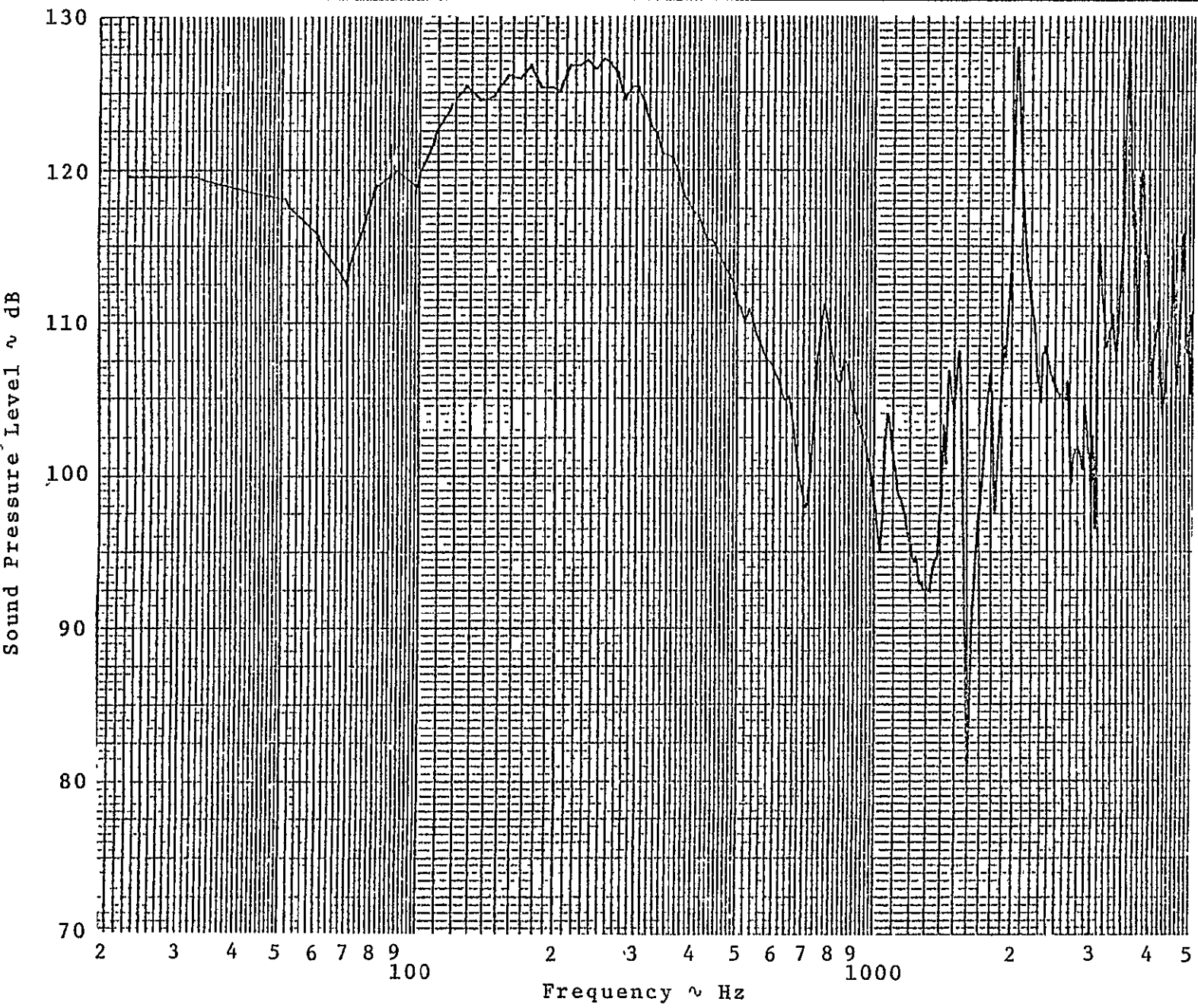
Frequency ~ Hz

Figure 3.1. The Frequency Response of a Speaker with No Acoustic Material between the Speaker and Specimen.

Figure 3.2. Frequency Response of a Speaker with a Foam Layer between the Speaker and Specimen.

CALC						REVISED	DATE
CHECK							
APPD							
APPD							

Sound Pressure Level ∿ dB

Frequency ∿ Hz
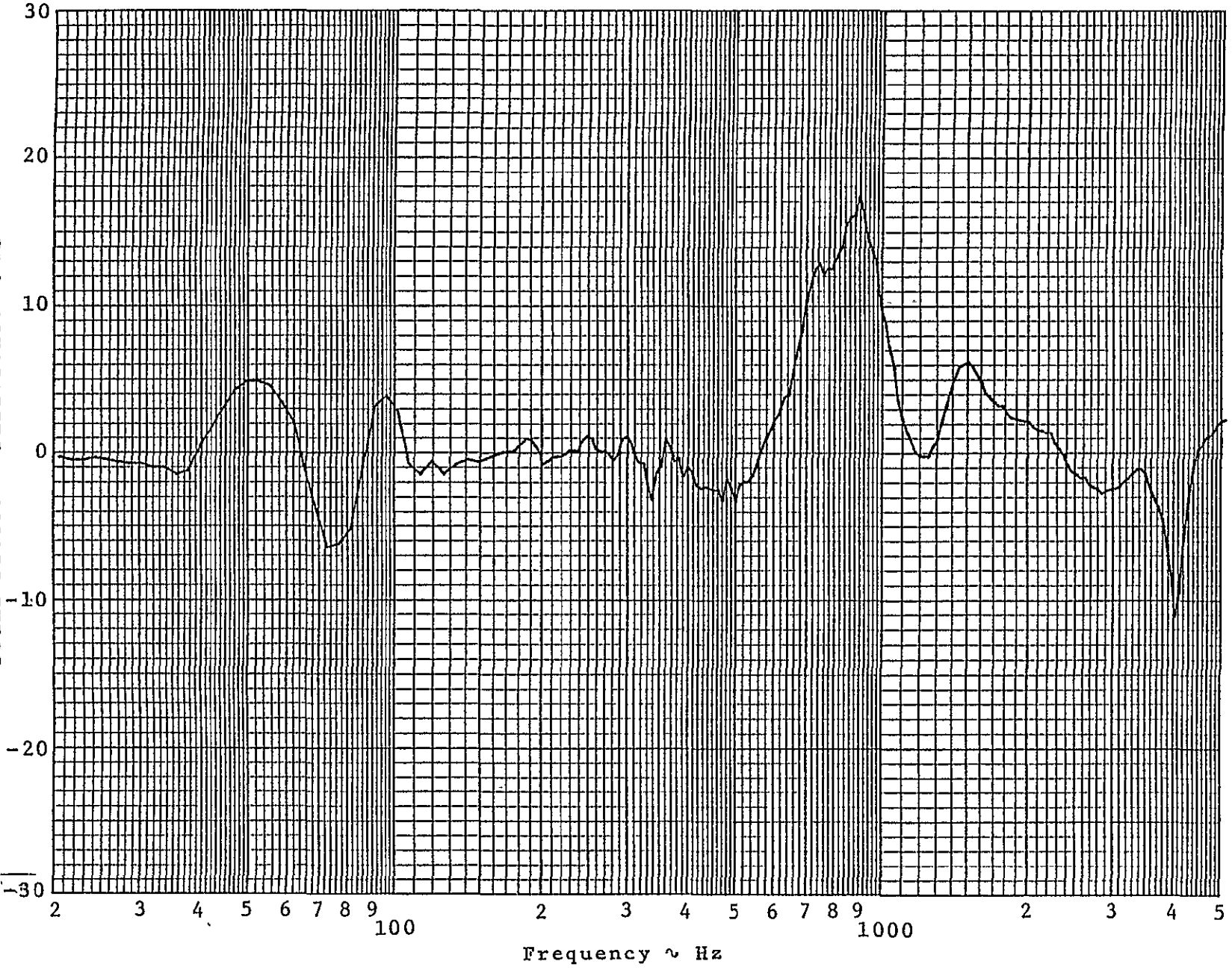
Figure 3.3. The difference between the sound radiated by speakers 1 and 5.

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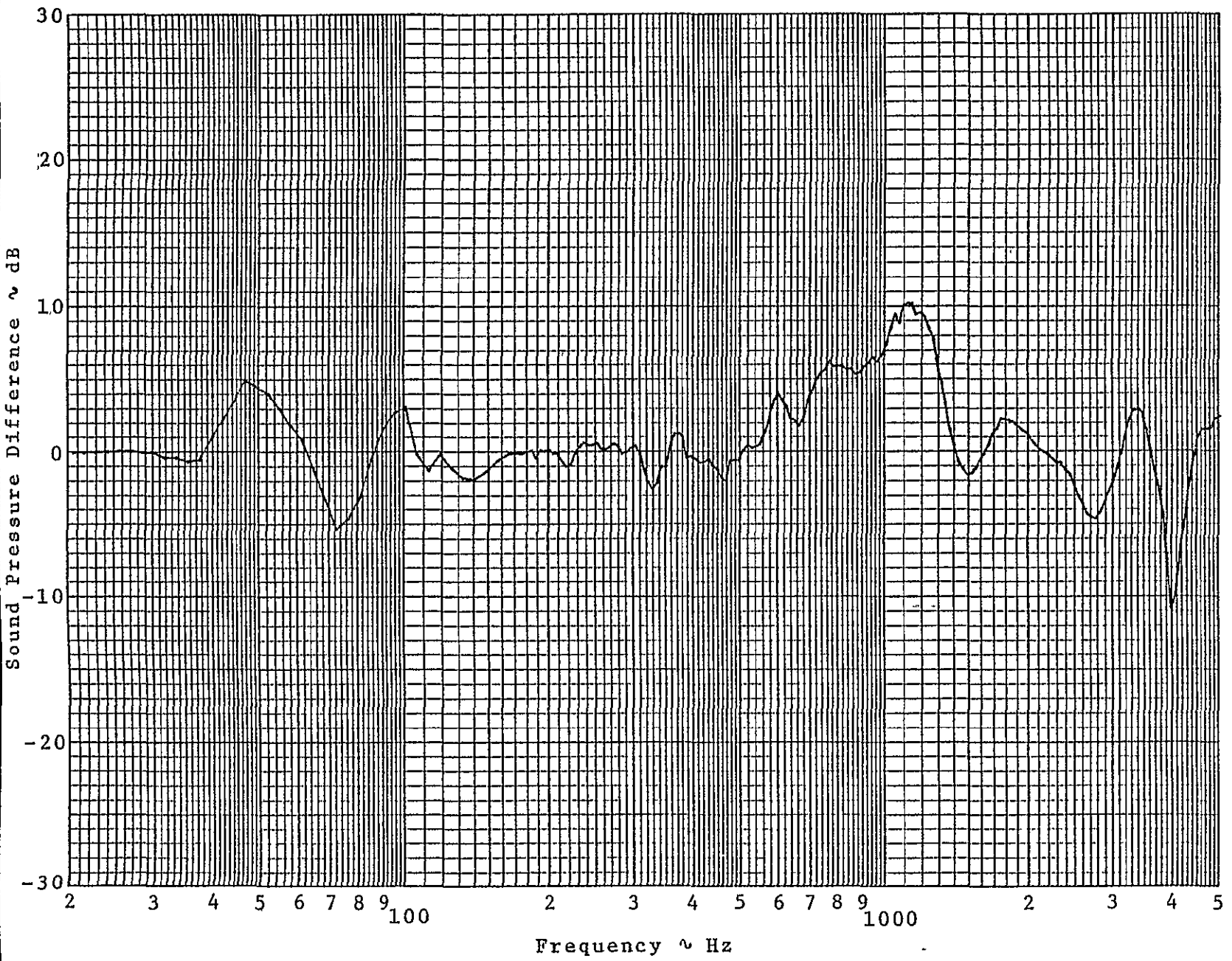
Figure 3.4. The difference between the sound radiated by speakers 2 and 5.

Figure 3.5. The difference between the sound radiated by speakers 3 and 5.

Sound Pressure Difference ~ dB

Frequency ~ Hz

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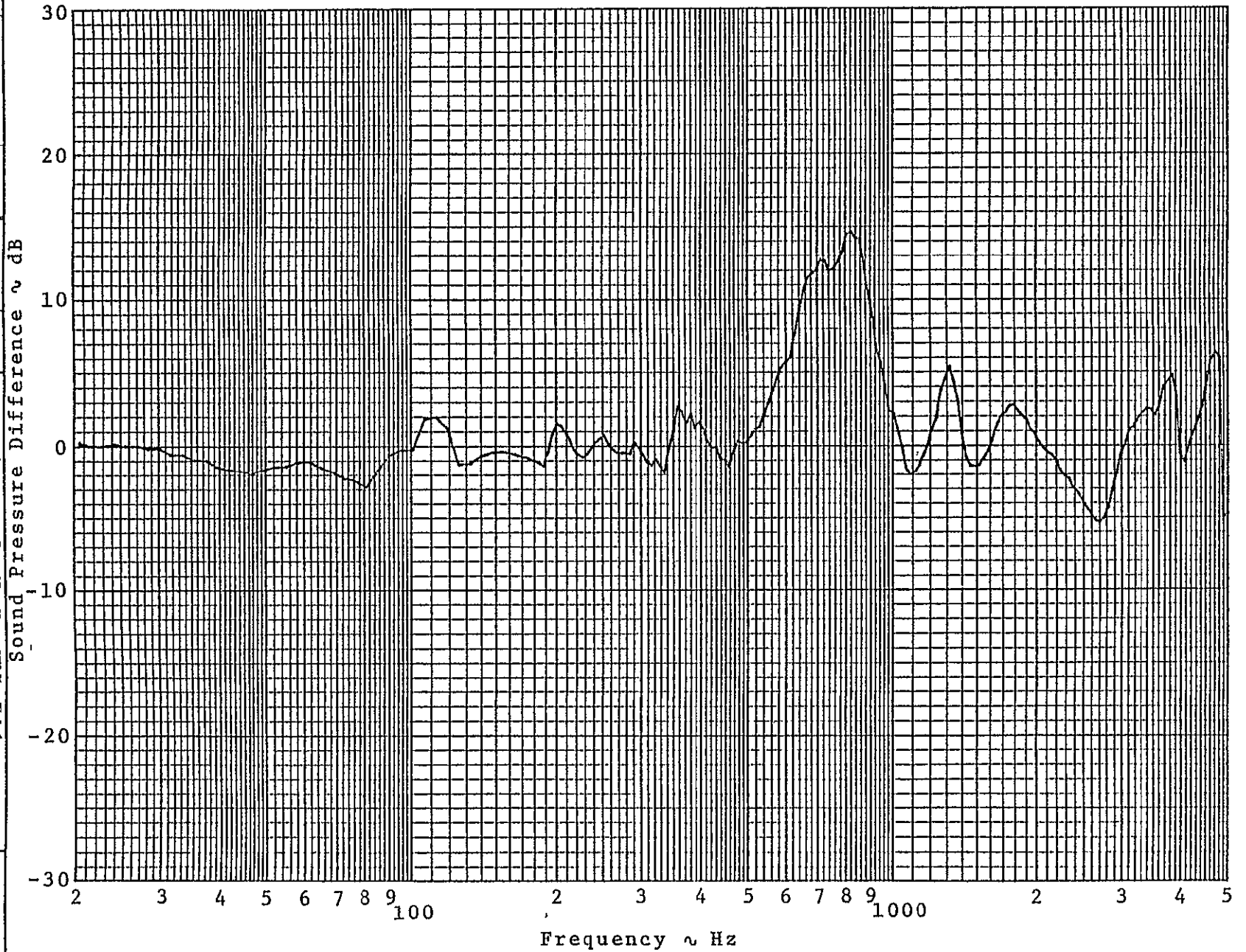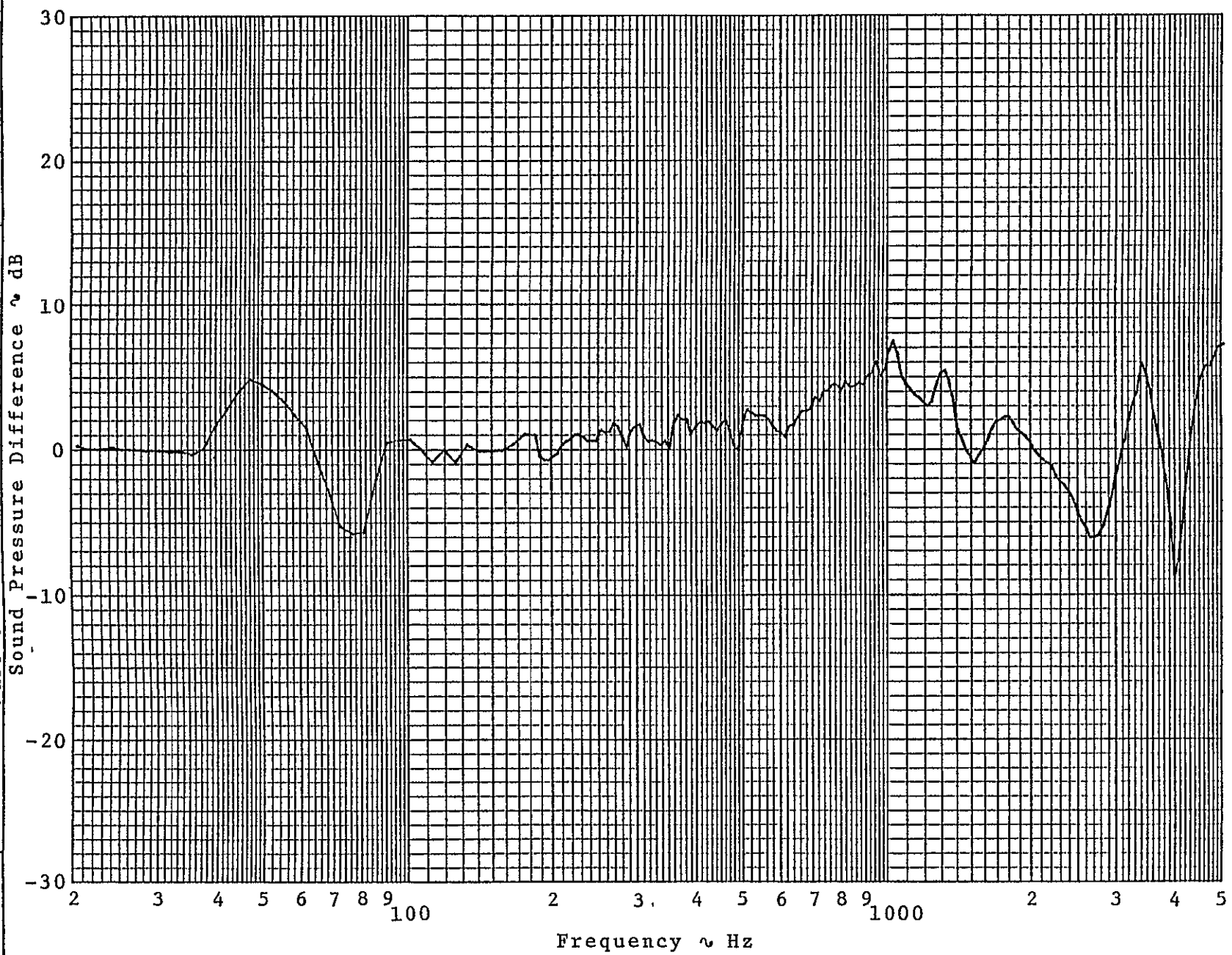
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Figure 3.6. The difference between the sound radiated by speakers 4 and 5.

Sound Pressure Difference ∿ dB

Frequency ∿ Hz

Sound Pressure Difference ~ dB

Figure 3.7. The difference between the sound radiated by speakers 6 and 5.

Frequency ~ Hz

Figure 3.8. The difference between the sound radiated by speakers 7 and 5.

Figure 3.9. The difference between the sound radiated by speakers 8 and 5.

Figure 3.10. The difference between the sound radiated by speakers 9 and 5.

To improve the overall frequency response of the speakers, an equalizer was put in series between the noise source and the power amplifier. The equalizer allows the amplitude of certain segments of the frequency spectrum to be varied. To determine the optimum settings, the noise source was directly fed into the analyzer where it was stored to be used as the reference signal. Next, the noise source was fed through the sound radiating system with the output of the source microphone connected to the analyzer. By comparing these two signals the equalizer could be adjusted to approximate the actual source. Figure 3.11 illustrates how the signal was modified to approximate the source signal.

3.3 Comparison of Theoretical and Experimental Results for Four Structural Panels

To determine the reliability of the KU–FRL test facility, the following four structural panels were tested: 0.016 aluminum, 0.032 aluminum, 0.020 steel, and 0.250 plexiglass. These specimens were tested in the plane wave tube using the procedures outlined in Appendix C. The resulting sound transmission loss characteristics of these panels were then compared with the accepted theories for panel behavior. The behavior of the test panels is illustrated in Figures 3.12 through 3.15.

The sound transmission loss (TL) curve for a particular panel is obtained in the following manner. The difference between the source and receiver microphone is computed. This value is commonly referred to as noise reduction (NR). Since the source microphone measures both the incident and reflected sound, a correction factor, K, needs to be added to the NR, to obtain the transmission loss.

$$TL = NR + K \ (dB) \qquad\qquad (3.1)$$

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Figure 3.11. The Results of Optimizing a Noise Source Using the Equalizer.

Temperature: 69°F
Angle of Incidence: 90°
Material: 2024-T3 Aluminum
Thickness: 0.016"
Pressure Differential: 0 psi

Noise Source: Pure Tone
Panel Treatment: None
Remarks: Stiffness Law
could not be accurately
plotted on this graph.

——— Mass Law

Figure 3.12. Sound Transmission
Loss Characteristics of a 0.016"
Thick Aluminum Panel of 18" x 18"
under Standard Conditions.

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BP — SSOL NOISSIMSNART TRANSMISSION LOSS — DP

FREQUENCY — Hz

Figure 3.13. Sound Transmission Loss Characteristic of a 0.032" Thick Aluminum Panel of 18" x 18" under Standard Conditions.

Temperature: 69°F   Pressure Differential: 0 psi
Angle of Incidence: 90°   Noise Source: Pure Tone
Material: 2024-T3 Aluminum Panel Treatment: None
Thickness: 0.032"   Remarks: None

———— Mass Law   ———— Stiffness Law

TRANSMISSION LOSS ~ DB

FREQUENCY ~ Hz

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Figure 3.14. Sound Transmission Loss Characteristics of a 0.020" Thick Steel Panel of 18" x 18" under Standard Conditions.

TRANSMISSION LOSS ~ DB

FREQUENCY ~ Hz

Temperature: 69°
Angle of Incidence: 90°
Material: Stainless Steel
Thickness: 0.020"
Pressure Differential: 0 psi

Noise Source: Pure Tone
Panel Treatment: None
Remarks: Stiffness Law
    could not be accurately
    plotted on this graph.

————— Mass Law

Figure 3.15. Sound Transmission Loss Characteristics of a 0.250" Thick Plexiglass Panel of 18" x 18" under Standard Conditions.

TRANSMISSION LOSS ~ dB

FREQUENCY ~ Hz

Temperature: 69°
Angle of Incidence: 90°
Material: Plexiglass
Thickness: 0.250"
Pressure Differential: 0 psi

Noise Source: Pure Tone
Panel Treatment: None
Remarks: Numbers indicate various resonance modes of the panel.

Mass Law
Stiffness Law
Equation 3.4

2,2   4,2   4,4
5,1
5,5
3,1
1,1

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$$K = 20 \log\left\{10^{\frac{NR}{20}} + 10^{\frac{-NR}{20}}\right\} - 6 - NR \text{ (dB)} \tag{3.2}$$

(Equations 3.1 and 3.2 can be found in References 4 and 7 respectively.)

Graphs of source and receiving microphone signals for the four test panels are included in Appendix A (Figures A.1 through A.4).

The various peaks and valleys in Figure 3.12 through 3.15 can be explained by looking at the vibrational modes of these panels. When a panel is subjected to a plane wave, it can be shown that a type of mode termed odd-odd (e.g., 3,1) will be excited. The reason that the large peaks occur in the transmission loss (TL) curves is due to the test specimen not being excited by a plane wave. Since it is virtually impossible to have nine identical speakers, it is not surprising that a perfect plane wave cannot be generated in this facility. However, by close examination of the TL curves, it is apparent that this facility does produce a close approximation to a plane wave. This is evident since the valleys appear to occur at odd-odd resonance modes only. In Figure 3.15 an attempt has been made to correlate the peaks and valleys with predicted frequencies for the various even-even and odd-odd panel modes.

In the stiffness controlled region (the area of the curve to the left of the main resonance) panel behavior is normally predicted using the equation given below (from Reference 3).

$$T_L(\frac{f_{1,1}}{4}, \text{stiffness}) = 20 \log(0.2048\rho_m hf_{1,1}) - 29 \text{ (dB)} \tag{3.3}$$

As seen in Figure 3.15, this equation does not accurately predict panel behavior. A more accurate method for predicting this region has

recently been derived by the KU-FRL research team. The main equation used is given below. The derivation of this equation is found in Reference 7.

$$TL(\text{stiffness}) = 20 \, \log \frac{\overline{m}|(f_{1,1}^{2} - f^{2})|}{f} - 20 \, (\text{dB}) \qquad (3.4)$$

The results of this equation are illustrated in Figure 3.15.

To the right of the main resonance is the mass controlled region of a panel. The sound transmission loss in this region is governed by the mass law, which states that panel motion is principally controlled by the surface weight of the panel.

$$TL = 10 \, \log \left\{ 1 + \left(\frac{\omega \rho_s}{2\rho_a c} \right)^2 \right\} (\text{dB}) \qquad (3.5)$$

(Equation 3.5 may be found in Reference 1.)

This relationship has been included in Figures 3.13 through 3.16.

In the mass controlled region of Figures 3.12 through 3.15, the transmission loss of each test specimen appears to be 2-3 dB's above the mass law. The reasons for the higher-than-predicted values are not fully understood and are currently being investigated. One idea being studied is that some of the sound passing through the panel is being absorbed by the foam before it reaches the receiving microphone.

Appendix B contains the methods used to calculate the major resonance, the mass law, and the TL in the stiffness controlled region. A sample calculation is also presented.

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CHAPTER 4

CONCLUSIONS

This section of the acoustic research project, from the beginning, has been concerned with three major objectives: (1) to design, construct, and calibrate the acoustic panel test facility within the time constraints outlined in Reference 8, (2) to build this facility for a reasonable cost, and most importantly (3) to show that the system provides reliable data.

The design, construction, and calibration of the KU-FRL acoustic panel test facility was accomplished during the nine month period 15 October 1976 through 15 July 1977. The system was fully operational on July 15 only one week after the scheduled completion date.

The total cost of constructing this facility (less electronics) was $2275.20. This figure is slightly higher than the $2000.00 budgeted for this phase of the project.

The results of testing four panels in the plane wave tube and the subsequent analysis of the behavior of these specimens indicate that the test facility generates data comparable with existing theories. In general the results were very satisfying. Certain anomalies in the final corrected transmission loss (TL) curves were not anticipated: specifically, the slightly higher-than-predicted values of TL in the mass controlled region and the peaks at the even-even resonance modes.

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APPENDIX A

<u>ORIGINAL TEST DATA</u>

Figure A.1. Sound Pressure Level at the Source and Receiving Microphone Locations for a 0.016 Aluminum Panel.

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Figure A.2. Sound Pressure Level at the Source and Receiving Microphone Locations for a 0.032 Aluminum Panel.

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	20 - 500 Hz	500 - 5K Hz
Source Attenuation	5 dB	0 dB
Receiver Gain	0 dB	20 dB
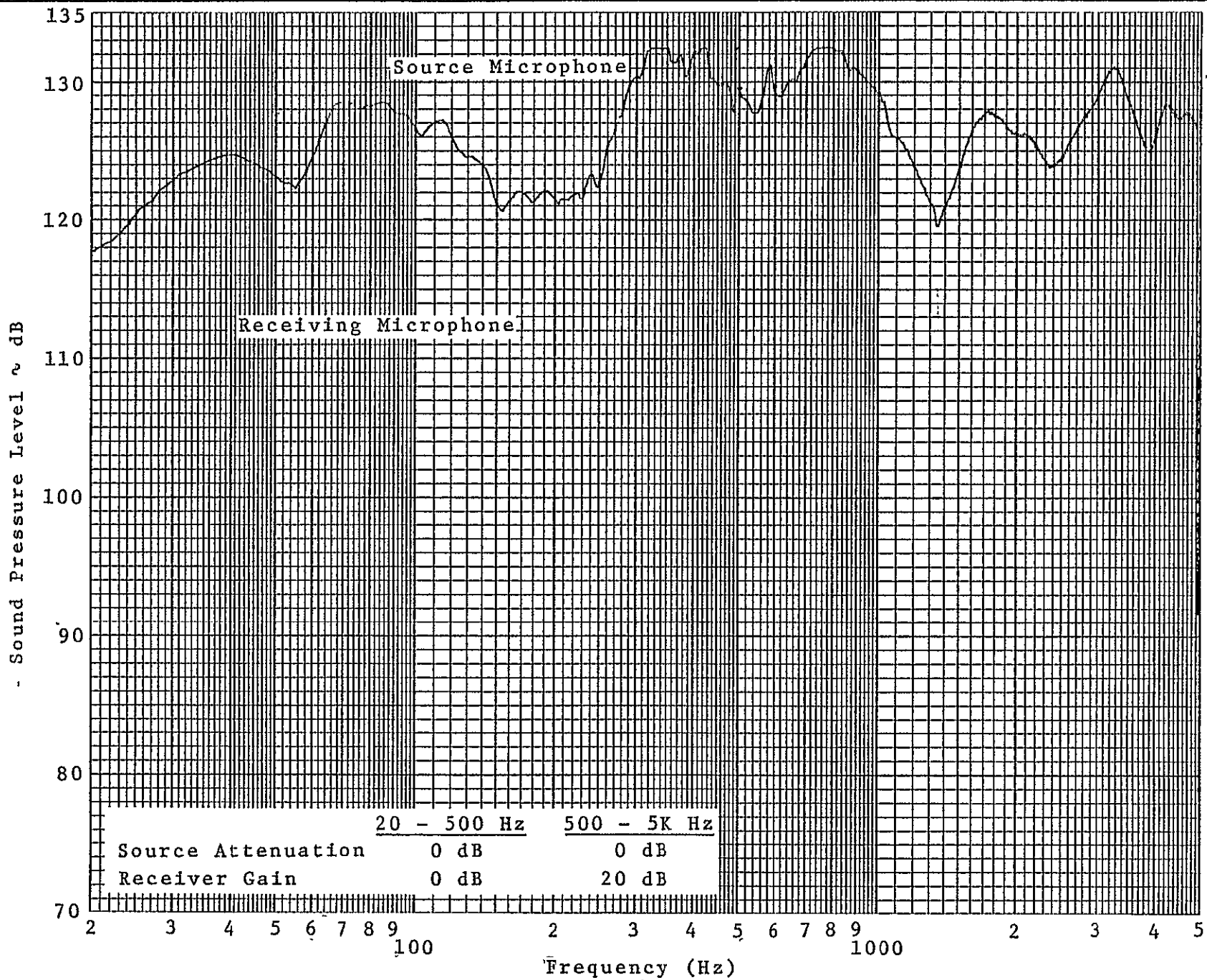
Figure A.3. Sound Pressure Level at the Source and Receiving Microphone Locations for a 0.020 Steel Panel.

	20 – 500 Hz	500 – 5K Hz
Source Attenuation	5 dB	0 dB
Receiver Gain	0 dB	20 dB

Source Microphone

Receiving Microhone

Sound Pressure Level ∿ dB

Frequency (Hz)

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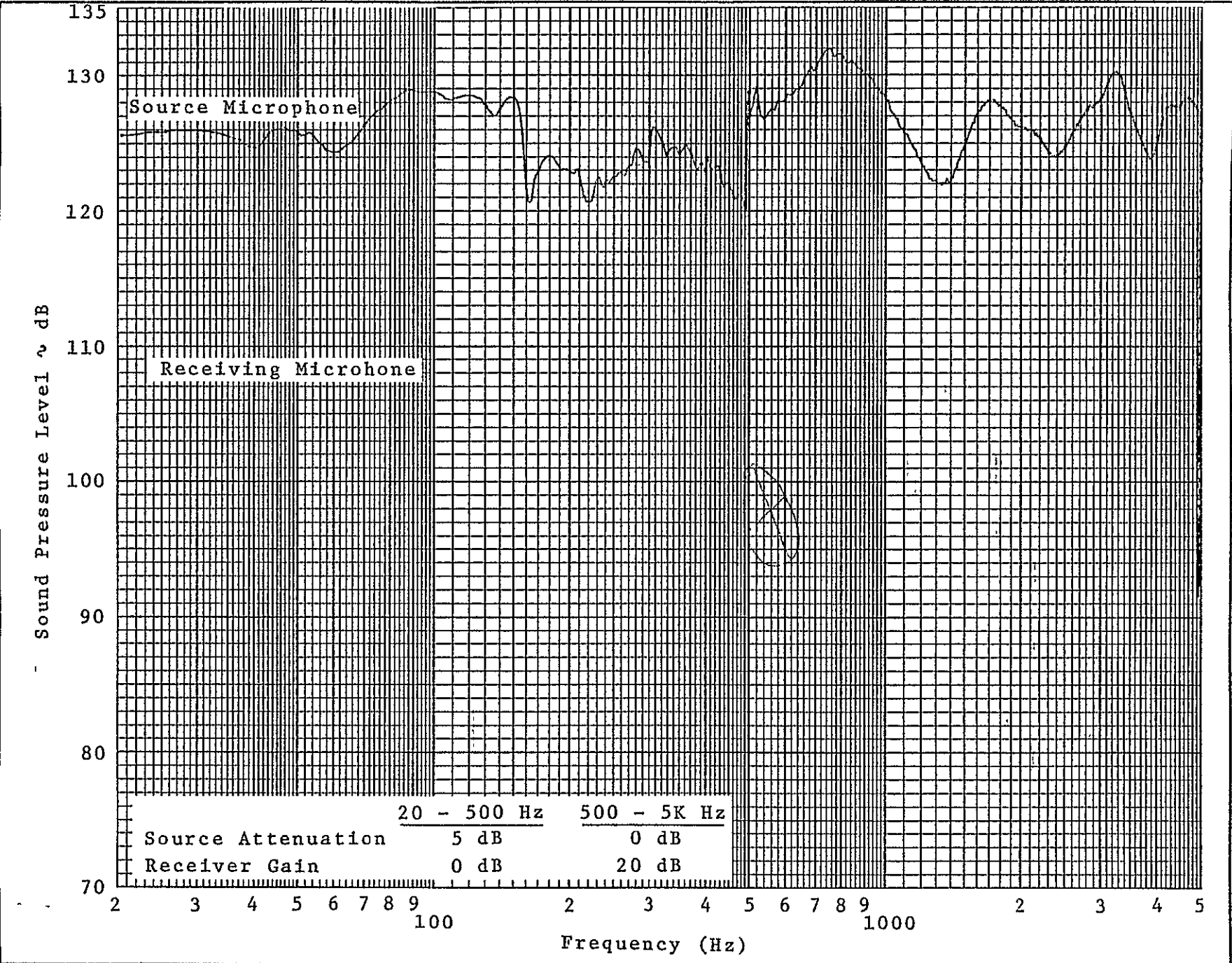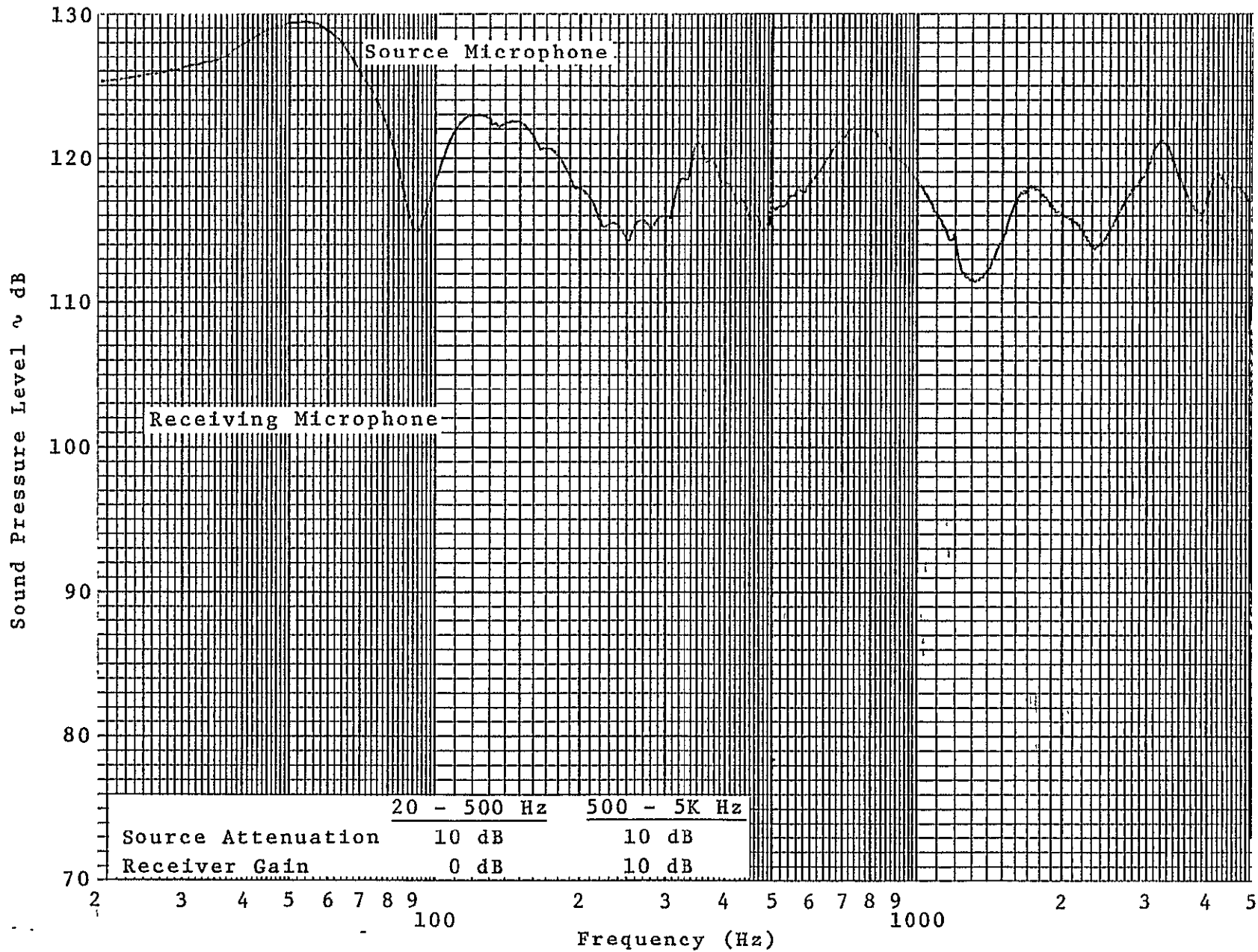
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Figure A.4. Sound Pressure Level at the Source and Receiving Microphone Locations for a 0.250 Plexiglass Panel.

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APPENDIX B

SAMPLE CALCULATIONS

APPENDIX B

SAMPLE CALCULATIONS

For rectangular panels clamped on all edges, the natural frequencies are given by the following expression (from Reference B.1).

$$\omega = \frac{\lambda_{m,n}}{b^2} \sqrt{\frac{D}{\bar{m}}} \quad (Hz) \qquad (B.1)$$

where

    b = panel length, m

    D = Flexural rigidity, Nm

      $= \dfrac{Eh^3}{12(1-\nu^2)}$

    E = Young's modulus, N/m^2

    h = Panel thickness, m

    ν = Poisson's ratio

    $\bar{m}$ = Mass of the panel per unit area, kg/m^2

$\lambda_{m,n} = \dfrac{\gamma h}{g}$

    γ = Specific weight of the material, N/m^3

    g = Gravitational acceleration, m/sec^2

$\lambda_{m,n}$ = Frequency parameter

In the case where panel properties are not know but the speed of compressional waves (C_L) is known, it can be shown (from Reference B.2) that:

$$\omega = \frac{\lambda_{m,n}}{b^2} \frac{C_L h}{\sqrt{12}} \quad (Hz) \qquad (B.2)$$

where

C_L = Speed of compressional waves, m/sec

$$= \frac{E}{\rho_m(1-\nu^2)}$$

ρ_m = Density of the panel material, kg/m^3

Equation B.1 can be derived from the governing equations of motion for a vibrating panel. The solution of these equations depends on the modes considered. The resulting increase of resonance frequencies of successive modes is expressed through increasing values of the frequency parameter λ. Table B.1 gives several values of λ for various resonance modes of a square clamped plate. These values are taken from Reference B.2. The frequencies at which these modes appear in the test panels are presented in Tables B.2 through B.5.

In the region above major resonance, the panel transmission loss is controlled by the surface weight of the panel. This is referred to as the mass law and is defined as follows (from Reference B.3):

$$TL = 10 \log\left\{1 + \left(\frac{\omega\rho_s}{2\rho_a c}\right)^2\right\} \text{ (dB)} \tag{B.3}$$

where

ω = Frequency

= $2\pi f$, rad/sec

ρ_s = Panel surface density

= $\rho_m h$, kg/m^2

ρ_m = Density of the panel material, kg/m^3

h = Thickness of panel, m

Table B.1 Values of λ for Various Resonance Modes

Notes: 1. From Reference B.2
        2. Values in parentheses are interpolated.
        3. Since panel and boundary conditions
            are fourfold symmetric, m and n are
            interchangeable.

m	n	λ
1	1	36
2	1	73
2	2	108
3	1	132
3	2	165
		210
3	3	220
		242
4	1	210
4	2	243
4	3	296
		309
4	4	371
		394
5	1	309
5	2	341
5	3	394
5	4	467
5	5	562
		565
		648
		811
		901
		981
6	1	(428)
6	2	458
6	3	510
6	4	584
6	5	(676)
6	6	793
7	7	1062
		1147
		1315
		1393
8	8	1371

Table B.2   Frequencies of Resonance Modes for 0.016 Aluminum

$$\omega = \frac{\lambda}{b^2} \frac{C_L h}{\sqrt{12}}$$

$$= 2.89\ \lambda\ \text{rad/sec.}$$

$$f = 0.46\ \lambda\ \text{Hz}$$

m	n	λ	f
1	1	36	17
2	1	73	34
2	2	108	50
3	1	132	61
3	2	165	76
		210	97
3	3	220	101
		242	111
4	1	210	97
4	2	243	112
4	3	296	136
		309	142
4	4	371	171
		394	181
5	1	309	142
5	2	341	157
5	3	394	181
5	4	467	215
5	5	562	259
		565	260
		648	298
		811	373
		901	414
		981	451
6	1	(428)	197
6	2	458	211
6	3	510	235
6	4	584	269
6	5	(676)	311
6	6	793	365
7	7	1062	489
		1147	528
		1315	605
		1393	641
8	8	1371	631

Table B.3 Frequencies of Resonance Modes for 0.032 Aluminum

$$\omega = \frac{\lambda}{b^2} \frac{C_L h}{\sqrt{12}}$$

$$= 5.76 \ \lambda \ \text{rad/sec.}$$

$$f = 0.92 \ \lambda \ \text{Hz}$$

m	n	λ	f
1	1	36	33
2	1	73	67
2	2	108	99
3	1	132	121
3	2	165	151
		210	193
3	3	220	202
		242	222
4	1	210	193
4	2	243	223
4	3	296	272
		309	283
4	4	371	340
		394	361
5	1	309	283
5	2	341	313
5	3	394	361
5	4	467	428
5	5	562	515
		565	518
		648	594
		811	743
		901	826
		981	899
6	1	(428)	392
6	2	458	420
6	3	510	468
6	4	584	535
6	5	(676)	620
6	6	793	727
7	7	1062	974
		1147	1051
		1315	1206
		1393	1277
8	8	1371	1251

$$\omega = \frac{\lambda}{b^2} \frac{C_L h}{\sqrt{12}}$$

$$= 3.543\ \lambda\ \text{rad/sec.}$$

$$f = 0.564\ \lambda\ \text{Hz}$$

m	n	λ	f
1	1	36	20
2	1	73	41
2	2	108	61
3	1	132	75
3	2	165	93
		210	119
3	3	220	124
		242	137
4	1	210	119
4	2	243	137
4	3	296	167
		309	174
4	4	371	209
		394	222
5	1	309	174
5	2	341	192
5	3	394	222
5	4	467	263
5	5	562	317
		565	319
		648	365
		811	457
		901	508
		981	553
6	1	(428)	241
6	2	458	258
6	3	510	288
6	4	584	329
6	5	(676)	381
6	6	793	447
7	7	1062	599
		1147	647
		1315	741
		1393	785
8	8	1371	773

Table B.5 Frequencies of Resonance Modes for 0.250 Plexiglass

$$\omega = \frac{\lambda}{b^2}\,\frac{C_L h}{\sqrt{12}}$$

$$= 15.785\ \lambda\ \text{rad/sec.}$$

$$f = 2.5122\ \lambda\ \text{Hz}$$

m	n	λ	f
1	1	36	90
2	1	73	184
2	2	108	272
3	1	132	332
3	2	165	415
		210	529
3	3	220	553
		242	608
4	1	210	529
4	2	243	610
4	3	296	745
		309	777
4	4	371	933
		394	989
5	1	309	776
5	2	341	857
5	3	394	990
5	4	467	1173
5	5	562	1412
		565	1419
		648	1628
		811	2037
		901	2263
		981	2464
6	1	(428)	1075
6	2	458	1151
6	3	510	1281
6	4	584	1467
6	5	(676)	1968
6	6	793	1992
7	7	1062	2668
		1147	2881
		1315	3304
		1393	3499
8	8	1371	3444

ρ_a = Density of air, kg/m^3

c = Speed of sound in air, m/sec

This equation as shown in Figures 3.12 through 3.15 is a straight line with a positive slope of 6 dB's per octave.

In the stiffness controlled region, two equations can be applied. The normal equation (from Reference B.5) used is of the form.

$$TL(\frac{f_{1,1}}{4}, \text{Stiffness}) = 20 \log(0.2048 \rho_m h f_{1,1}) - 29 \text{ (dB)} \qquad \text{(B.4)}$$

where

ρ_m = Density of panel material, kg/m^3

h = Panel thickness, m

$f_{1,1}$ = Fundamental resonance frequency.

As discussed in section 3.3, a more accurate prediction method for the stiffness region can be expressed as:

$$TL(\text{Stiffness}) = 20 \log \frac{\overline{m}|f_{1,1}^2 - f^2|}{f} - 20 \text{ (dB)} \qquad \text{(B.5)}$$

where

$\overline{m}$ = Mass of the panel per unit area, kg/m^2

$\quad = \frac{\gamma h}{g}$

γ = Specific weight of the material, N/m^3

h = Panel thickness, m

g = Gravitational acceleration, m/sec^2

$f_{1,1}$ = Fundamental resonance frequency, Hz

f = Any frequency in the stiffness region, Hz

This equation is used to determined the TL of a panel in the stiffness region on a point by point basis.

EXAMPLE: 0.016 Aluminum

Material properties of 2024-T3 aluminum alloy.

$h = 0.016$ inch

$E = 10.5 \times 10^6$ psi

$\nu = 0.33$

$\rho_m = 0.10$ lbs/inch^3

$\left.\vphantom{\begin{array}{c}1\\1\\1\\1\end{array}}\right\}$ From Reference B.4

$C_L = 5150$ m/sec

$\rho_m = 2700$ kg/m^3

$\left.\vphantom{\begin{array}{c}1\\1\end{array}}\right\}$ From Reference B.3 (Table 11.4, page 308)

For the first resonance mode a panel (from Table B.1)

$$\lambda_{1,1} = 36.0$$

Using the value of C_L, $\omega_{1,1}$ can be computed as follows:

$$\omega_{1,1} = \frac{\lambda_{1,1}}{b^2} \frac{C_L h}{\sqrt{12}}$$

$$= \frac{36.0}{\left(\frac{18 \text{ in}}{39.37 \text{ in/m}}\right)^2} \times \frac{(5150 \text{ m/sec})\left(\frac{0.016 \text{ in}}{39.37 \text{ in/m}}\right)}{\sqrt{12}}$$

$$= 105 \text{ rad/sec.}$$

$$= 16.7 \text{ Hz.}$$

Using the material properties, $\omega_{1,1}$ can be computed as follows

$$\omega_{1,1} = \frac{\lambda_{1,1}}{b^2} \sqrt{\frac{D}{m}}$$

$$D = \frac{Eh^3}{12(1-\nu^2)}$$

$$= \frac{(10.5 \times 10^6 \text{ lbf/in}^2)\left(6894 \frac{\text{N/m}^2}{\text{lbf/in}^2}\right)[(0.016 \text{ in})(0.0254 \text{ m/in})]^3}{12(1-.33^2)}$$

$$= 0.454 \text{ Nm}$$

$$\overline{m} = \frac{\gamma h}{g}$$

$$= (1/9.807 \text{ m/sec}^2) \times (0.10 \text{ lbs/m}^3) \times (6.102 \times 10^4 \text{ m}^3/\text{in}^3) \times$$

$$(4.448 \text{ kgm/sec}^2/\text{lb}) \times (0.016 \text{ in}) \times (0.0254 \text{ m/in})$$

$$= 1.125 \text{ kg/m}^2$$

Therefore

$$\omega_{1,1} = \frac{36}{\left(\frac{18 \text{ in}}{39.37 \text{ in/m}}\right)^2} \sqrt{\frac{0.454 \text{ Nm}}{1.125 \text{ kg/m}^2}}$$

$$= 109.46 \text{ rad/sec}$$

$$= 17.4 \text{ Hz}$$

The transmission loss of this panel at 400 Hz is:

$$TL = 10 \log[1 + (\frac{\omega \rho_s}{2\rho_a c})^2] \text{ (dB)}$$

where

$$\omega = 2\pi f$$

$$= 2\pi(400)$$

$$= 2513.3 \text{ rad/sec}$$

$$\rho_s = \rho_m h$$

$$= (2700 \text{ kg/m}^3)(0.016 \text{ in})(0.0254 \text{ m/in})$$

$$= 1.10 \text{ kg/m}^2$$

$$c = (1116 \text{ ft/sec})(0.3049 \text{ m/ft})$$

$$= 340.3 \text{ m/sec}$$

$$\rho_a = (0.125 \text{ kg sec}^2/\text{m}^4)(9.81 \text{ m/sec}^2)$$

$$= 1.226 \text{ kg/m}^3$$

Therefore

$$TL = 10 \log\left[1 + \left(\frac{(2513.3)(1.10)}{(2)(1.226)(340.3)}\right)^2\right]$$

$$= 10.76 \text{ dB at } 400 \text{ Hz}$$

Since the slope of the mass law is 6 dB's/octave

$$TL(800 \text{ Hz}) = 10.76 + 6$$

$$= 16.76 \text{ dB}$$

$$TL(200 \text{ Hz}) = 10.76 - 6$$

$$= 4.76 \text{ dB}$$

Table B.6 presents a summary of the important material properties and resulting acoustic characteristics of the four test panels. The acoustic characteristics ($f_{1,1}$ and TL according to the mass law) are shown in Figures 3.12 through 3.15.

Table B.6 Summary of the Material Properties and Acoustic Characteristics of the Four Calibration Panels

Quantity	Units	0.016 Aluminum	0.032 Aluminum	0.020 Steel	0.250 Plexiglass
h	inches	0.016	0.032	0.018	0.250
E	lbs/in^2	10.5×10^6	10.5×10^6	*	*
ν		0.33	0.33	*	*
ρ	lbs/in^3	0.10	0.10	*	*
c_L	m/sec	5150	5150	5050	1800
ρ_m	kg/m^3	2700	2700	7700	1150
C	m/sec	340.3	340.3	340.3	340.3
$\lambda_{1,1}$		36.0	36.0	36.0	36.0
$f_{1,1}$	Hz	16.7	34.8	20.3	90.5
TL (200 Hz)	dB	4.76	10.5	15.5	20.9
TL (400 Hz)	dB	10.76	16.5	21.5	26.9
TL (800 Hz)	dB	16.76	22.5	27.5	32.9
TL ($f_{1,1}/4$)	dB	**	1.1	**	13.4

Note: The resonant frequency ($f_{1,1}$) of the panels was calculated using equation B.2.

*These values were not available.
**These values were not calculated as they could not be plotted on Figures 3.12 through 3.14.

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B.3 Beranek, Leo L., Noise and Vibration Control, McGraw Hill Inc.,
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B.5 Franken, Peter A., et al., "Methods of Flight Vehicle Noise Pre-
     diction," WADC Technical Report 58-343, November 1958.

APPENDIX C

COMPILATION OF RECOMMENDED CALIBRATION,

TEST AND DATA REDUCTION PROCEDURES

APPENDIX C

COMPILATION OF RECOMMENDED CALIBRATION,

TEST AND DATA REDUCTION PROCEDURES

This Appendix presents recommended calibration, test and data reduction procedures, intended to (1) facilitate research work, (2) assure reliable experimental results and (3) prevent possible damage to electronic equipment. The procedures outlined here are based on equipment handbooks, conversations with electronic experts and experiences of the noise research team. The recommendations concern research work being conducted at the time of this writing (August 1977). Any changes or additions to the current scope will require new or modified recommendations.

The following procedures are included:

1. Calibration of the SD-335 Analyzer Scope

    X-axis

    Y-axis

2. Analyzer, Sweep Oscillator and X-Y Plotter Scaling and Calibration

3. Panel Test Procedures

    A. Using Sweep Oscillator

    B. Using White Noise

    C. Using Recorded Actual Aircraft Noise

4. Manual of HP-9825A Computer Program for Reducing Test Data

Also included are the following items:

5. Example of a Specimen Log Sheet

6. Example of a Test Log Sheet

1. Calibration of the SD-335 Analyzer Scope

X-Axis Calibration

(8) Select Y LOG to enhance markers.

(9) Adjust until the 10 frequency markers are on the 10 vertical graticule lines of the display.

(18) Select Y LIN (Button out).

(23) Using ZERO button in CAL section adjust sweep to left and right side of vertical line on scope.

(12) Readout should be 10% Full Scale Frequency.

(11) Using the CURSOR control move the intensified dot to the top of the first frequency marker.

(1) ANALYZER   (2) OSCILLOSCOPE   (3) AVERAGER

(13) Select HARMONIC.

(21) Select X LOG Y LOG (Button in

(10) Select Hz (Button out).

(20) Select Hz (Button out)

(16A) Select AMPL (Button in).

(14A) Adjust until 10 intensified dot are located exactly on the 10 frequency markers

(15) Release (Button out).

(6) Select FREQ MARKS to place 10 frequency markers on display at 10% intervals

(5) Select SPECT to change from time to frequency domain.

(22) Select FREQ.

(1) Select SPECT to apply square wave calibration signal to input.

(3) Adjust for bright signal

(2B) Display should be square wave If not, check TRIGGER level Should be : mid range

(16B) Select SPECT.

(4) Adjust for sharply focused signal.

(2A) Select TIME.

(17) Digital Readout should by 0 dB. If not, adjust for 0 dB

(19) Digital Readout should be 100%. If not, adjust for 100%.

(14B) Looking at the two leftmost frequencies marks and using a screwdriver on the FREQ CAL LO screw, adjust these two signals such that they look like Figure 1 below. Repeat this for the two rightmost signals using the FREQ CAL HI screw

(7) Select Oper ,Calibration frequency components should disappear, leaving frequency markers

Figure D.1 Frequency marks after adjustment.

Y-Axis Calibration

Select 10 Vrms.   ⑤

Select 1 Vrms   ⑦

Adjust until signal baseline
is at 0 and amplitude of
fundamental frequency is Full Scale.   ③ₐ

④ Select LOG
(Button In)

② Select LIN
(Button Out).

① Select
(Button In)

⑥ Adjust fundamental
at 256 Hz to −40 dB

⑧ Adjust fundamental
at 256 Hz to 0 dB

③b Lin Scale.

⑨b Log Scale. †
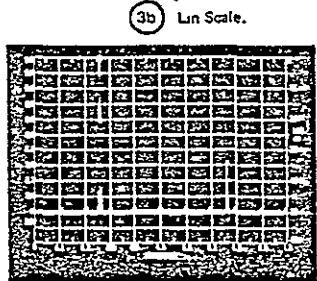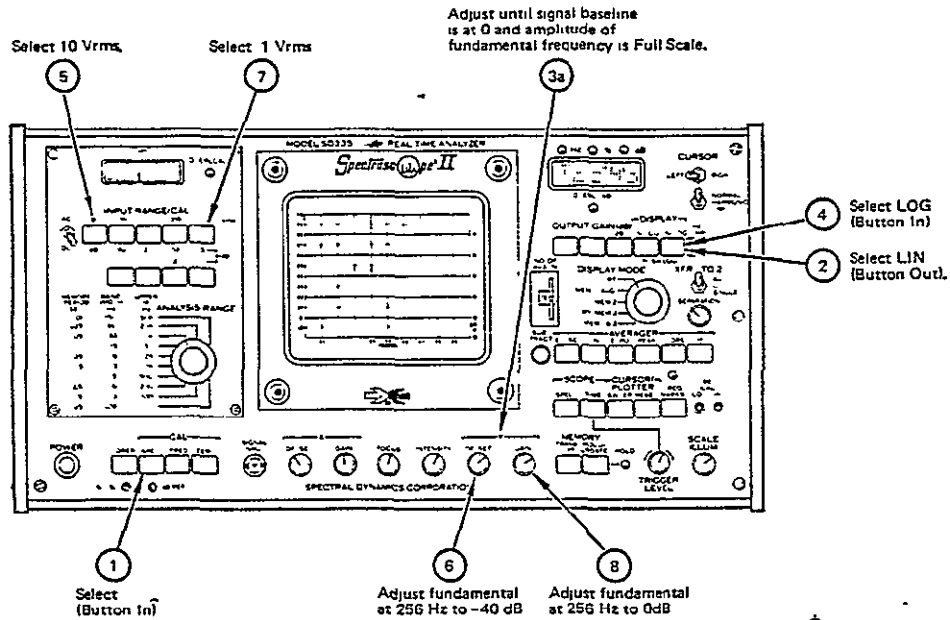
Repeat steps 5, 6, 7 AND 8
until the fundamental is at
−40 dB and 0 dB, and there
is no interaction between steps   ⑨ₐ

0 dB ATTENUATION
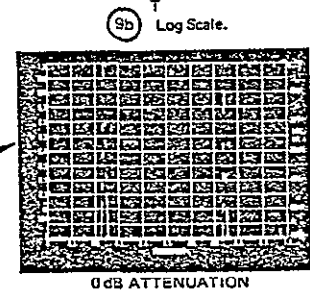
* Check this full scale to zero calibration by momentarily pushing in and
releasing the CAL ZERO button. When the ZERO button is pressed,
only a baseline should be visible on the scope. When the ZERO button
is out, the calibration signal should be full scale

⑩

Select 0, 10, 20 30 dB
Fundamental should drop 2 divisions
each time the calibration signal is
attenuated by an additional 10 dB

20 dB ATTENUATION
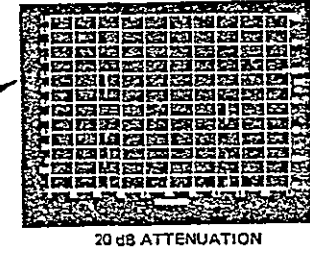
† The voltage of the input calibration signal is adjusted so that the amplitude of the fundamental frequency of the square wave is 100 mVrms.
The third harmonic (viewed at 76.8% of full scale) is always approximately 10 dB down from the fundamental when viewing the Y-axis data
on a log scale

2. Analyzer, Sweep Oscillator and X-Y Recorder Scaling and Calibration

First: Turn on all equipment (except Crown power amplifier) and let it warm up for approximately 1 minute.

Setting Up

1. Attach clean sheet lin-log paper, left edge against black post, using "Chart Hold" switch. Freq. axis should be horizontal (left to right).

2. Real Time Analyzer settings should be:

Input Range	.1 V_{RMS}
Analysis Range	5K
"CAL" Group	"OPER" button in
Switch under Cursor Switch	Normal
Output Gain	0 dB
Display	X log (in), Y log (in)
Hz/AMPL	Hz (button out)
Display Mode	RT
XFR 1 to 2	Off
Averager	(setting not important here)
"Scope"	"SPECT" button in
Cursor/Plotter	(All buttons out)

3. Sweep Oscillator Settings:

Multiplier (A)	1
Multiplier (B)	10
Sweep Rate	(setting not important here)
Sweep Control	"LINEAR SWEEP", "SINGLE"
Function	Sine Wave (~)
Sweep Buttons	push "RESET DOWN" button

4. X-Y Recorder Settings: <u>X</u> <u>Y</u>

    Polarity   + RT   + UP

    Response   SLOW   SLOW

    Range   .5 V/IN   .5 V/IN

    Line   ON

    Chart   HOLD

    Servo   STAND BY

    Pen   LIFT

5. Connect Output of Sweep Oscillator (coaxial cable, shield grounded) to "SIGNAL INPUT" of Analyzer.

6. Press "FREQ" button ("CAL" section).

7. Adjust "X-OFFSET" and "X-GAIN" until beginning of green line on scope coincides with "0" on frequency scale, and end of line with "1.0".

8. Press "SPECT" button ("CAL" section).

9. Adjust "Y-OFFSET" and "Y-GAIN" until top of vertical line on scope coincides with "1.0" on vertical scale, and bottom (horizontal line) with "0".

10. Press "OPER" button.

<u>Adjustment of Sweep Oscillator Limits</u>

11. Set Analyzer cursor to 10 Hz (digital readout).

12. Press X Lin (button out) (Analyzer).

13. Adjust "LOWER SWEEP LIMIT" on Sweep Oscillator (using screw driver) until test signal (10 Hz) peak on Analyzer scope coincides with cursor dot.

14. Press X Log (Button in) (Analyzer).

15. Set Analyzer cursor to 5000 Hz (digital readout).

16. Press "RESET UP" button on Sweep Oscillator.

17. Adjust "UPPER SWEEP LIMIT" on Sweep Oscillator until test signal
     peak on Analyzer scope coincides with cursor dot.

18. Press "RESET DOWN" button on Sweep Oscillator.

Frequency Adjustment X-Y Plotter

19. Set cursor to 500 Hz.

20. Be sure plotter pen in inserted; remove cap from pen.

21. Turn X-Y Plotter servo switch "ON".

22. Move Sweep Oscillator control knob from "LINEAR SWEEP, SINGLE"
     to "MAN".

23. Adjust "FREQ ADJ" control on Sweep Oscillator until test signal
     peak on analyzer scope coincides with cursor dot. This will
     move X-Y plotter pen into grid area of graph paper.

24. Adjust "ZERO" knob in "X" section of plotter controls until
     pen makes a dot on the 500 Hz line of lin-log graph paper. To
     check dot location, move "PEN" switch on plotter to "RECORD",
     then return switch to "LIFT" position. Turn servo switch off.

25. Set Analyzer cursor to 5000 Hz.

26. Turn X-Y plotter servo switch "ON".

27. Pen should now make a dot on the 5000 Hz line on graph paper
     when "PEN" switch is momentarily moved to "RECORD". If
     necessary, adjust pen position with the "CAL" knob on Recorder's
     X "RANGE" control.

28. Move cursor (on Analyzer) to 500 Hz. Recorder pen should move to 500 Hz line. Check pen's exact position by switching pen control to "RECORD". If necessary, adjust pen position with X "ZERO" knob (located on the recorder).

29. Repeat steps 21 and 27 until pen position is correct at both 500 and 5000 Hz.

Amplitude Adjustment of X-Y Plotter

30. Connect microphone power supply output with analyzer input.

31. Determine sound pressure level of piston phone by subtracting atmospheric correction (gauge) from specified reference value (= 124 dB).

32. Connect piston phone to source or receiver microphone.

33. Move the intensified dot in the scope, using the "CURSOR", to the peak of the calibration signal.

34. Energize plotter servo. Plotter pen will move to peak of calibration signal.

35. Adjust Plotter Y - "GAIN" knob such that pen moves to cal. level on a predetermined vertical scale.

36. Press 20 dB "INPUT RANGE/CAL" button on Analyzer.

37. Adjust Plotter Y - "ZERO" knob such that pen moves to cal. level - 20 dB on predetermined vertical scale.

38. Press 0 dB "INPUT RANGE/CAL" button on Analyzer.

39. Repeat steps 34 thru 37 until pen position is correct at both cal. level and cal. level - 20 dB.

3. Panel Test Procedures

A) Using Sweep Oscillator

1. Switch equipment on (except Crown amplifier) and let it warm
    up for approximately 1 minute. Check equalizer setting.

2. Calibrate Analyzer, set limits of Sweep Oscillator (10–5000 Hz)
    and scale X–Y Plotter as described in sections 1 and 2.

3. Install panel. Adjust clamps.

4. Connect output Microphone Power Supply with input Anlayzer, and
    output Sweep Oscillator with input Equalizer.

5. Set equalizer gain to 0 dB, Sweep Oscillator level to 4–5.

6. Set "SWEEP RATE" (Sweep Oscillator) to 30 Hz/sec.

7. Set "ANALYSIS RANGE" knob (Analyzer) to 5K.

8. If small panel TL values are expected: press 0 dB "INPUT
    RANGE/CAL" knob (Analyzer). For high TL values: use 10 dB
    attenuation.

9. Set knob on Microphone Power Supply such that source microphone
    will be analyzed.

10. Switch on Crown amplifier. Set level knob half way.

11. Increase output level of Sweep Oscillator such that VU–meter of
    Equalizer will not indicate an overload at any frequency. Use
    "RESET-UP" and "RESET-DOWN" buttons (Sweep Oscillator) to check
    complete frequency range.

13. Press "RESET-DOWN" button (Sweep Oscillator).

14. Turn "DISPLAY MODE" knob to: "MEM 1".

15. Press consecutively: "STORE"

```
                              "ERASE"
                              "PEAK"
(Analyzer)


16.   Press "SWEEP-UP" (Sweep Oscillator).


17.   When sweep is completed:  Press consecutively:

                         "STORE"            (Analyzer)
                         "RESET"            (Analyzer)
                         "SPECT" ("SCOPE")  (Analyzer)


18.   Using "CURSOR", move intensified dot to 500 Hz (Analyzer).


19.   Energize plotter servo, and press:  "SWEEP" (Analyzer).


20.   When plot is completed:  de-energize plotter servo.


21.   Change Microphone Power Supply knob to analyze receiver
      microphone.


22.   Press 0 dB "INPUT RANGE/CAL" knob (Analyzer).


23.   If moderate panel TL values are expected:  press 0 dB "OUTPUT
      GAIN" button (Analyzer).  For high values use 10 dB gain.  For
      very high values use 20 dB gain.  (Be sure not to overload
      Analyzer).


24.   Press consecutively:  "STORE"
                            "ERASE"
                            "PEAK"
(Analyzer)


25.   Press "SWEEP-UP" (Sweep Oscillator).


26.   When sweep is completed:  Press consecutively:

                         "STORE"            (Analyzer)
                         "RESET"            (Analyzer)
                         "SPECT ("SCOPE")   (Analyzer)
```

27. Using "CURSOR", move intensified dot to 500 Hz (Analyzer).

28. Press 0 dB "OUTPUT GAIN" button (Analyzer).

29. Repeat steps 19 and 20.

30. Set "ANALYSIS RANGE" button (Analyzer) to 500.

31. Change "SWEEP RATE" to 5 Hz/sec. (Sweep Oscillator).

32. Press consecutively: "STORE"
                           "ERASE"
                           "PEAK"
(Analyzer)

33. Press "SWEEP-UP" (Sweep Oscillator).

34. When sweep is completed: Press consecutively:

                       "STORE"   (Analyzer)
                       "RESET"   (Analyzer)
                       "SPECT" ("SCOPE")   (Analyzer)

35. Using "CURSOR", move intensified dot to 50 Hz.

36. Energize plotter servo and using the "ZERO" knob in the "X"
    section of the recorder controls adjust until the pen makes
    a dot on the 50 Hz line of the lin-log graph paper. To check
    dot location, move "PEN" switch on plotter to "RECORD",
    then return switch to "LIFT" position. Move "CURSOR" to 20 Hz.

37. Energize plotter servo, and press: "SWEEP" (Analyzer).

38. When plot is completed: de-energize plotter servo.

39. Change Microphone Power Supply knob to analyze source microphone.

40. Press "INPUT RANGE/CAL" button to the setting used for the 500-
    5000 range analysis.

41. Press consecutively: "STORE"
                        "ERASE"
                        "PEAK"
(Analyzer)

42. Press "SWEEP-UP" (Sweep Oscillator).

43. When sweep is completed: Press consecutively:

                        "STORE"   (Analyzer)
                        "RESET"   (Analyzer)
                        "SPECT"("SCOPE")   (Analyzer)

44. Using "CURSOR", move intensified dot to 20 Hz.

45. Press 0 dB "OUTPUT GAIN" button (Analyzer).

46. Energize plotter servo, and press: "SWEEP" (Analyzer).

47. When plot is completed: de-energize plotter servo.

48. Using "CURSOR", move intensified dot to 500 Hz.

49. Energize plotter servo and using "ZERO" knob in the "X" section
    of the plotter controls adjust until pen makes a dot on the
    500 Hz line of the lin-log graph paper. To check dot location,
    move "PEN" switch on plotter to "RECORD", then return switch to
    "LIFT" position.

50. Change "SWEEP RATE" to 30 Hz/sec. (Sweep Oscillator)

51. To test another panel repeat steps 7-49.

B)   Using White Noise

1.   Switch equipment on (except Crown amplifier) and let it warm
      up for approximately 1 minute.

2.   Calibrate Analyzer and Scale X-Y plotter as described in sections
      1 and 2.

3.   Install panel. Adjust clamps.

4.   Connect output of White Noise generator to the input of the
      equalizer and output of Microphone Power Supply to the input of
      the Analyzer.

5.   Set equalizer gain to 0 dB, White Noise generator to 1 volt.

6.   Set knob on Microphone Power Supply such that the source
      microphone will be analyzed.

7.   Set "ANALYSIS RANGE" knob (Analyzer) to 5K.

8.   Switch on Crown amplifier. Increase level to get a high signal
      (but no overload) on the Analyzer's scope.

      If greater signal strength is needed : increase, in order, the
      controls up to the stated values.

      a) Increase White Noise generator up to 2 volts,

      b) Increase equalizer gain up to +15 dB,

      c) Increase White Noise generator up to 3 volts.

9.   Turn "DISPLAY MODE" knob to "MEM 1" (Analyzer).

10.   Select the number of averages to be taken (normally 256).

11.   Press consecutively: "STORE"
                             "ERASE"
                             "LIN"
      (Analyzer).

12. When red light below "STORE" button lights analysis is complete: press consecutively:

"STORE"	(Analyzer)
"RESET"	(Analyzer)
"SPECT"	(Analyzer)

13. Using "CURSOR", move intensified dot to 20 Hz.

14. Energize plotter servo, and press: "SWEEP" (Analyzer).

15. When plot is completed: de-energize plotter servo.

16. Change Microphone Power Supply knob to analyze receiver microphone.

17. If moderate TL values are expected: press 0 dB "OUTPUT GAIN" button (Analyzer). For higher values use 10 dB gain. For very high values use 20 dB gain. (Be sure not to overload Analyzer).

18. Repeat steps 9-13.

19. Press 0 dB "OUTPUT GAIN" (Analyzer).

20. Energize plotter servo, and press: "SWEEP" (Analyzer).

21. When plot is completed: de-energize plotter servo.

22. To test another panel repeat steps 6-21.

C)   Using Recorded Actual Aircraft Noise

C.1   Use of Nagra Recorder

1.   Check batteries of Recorder

2.   Load tape onto Recorder

3.   Select proper speed (usually 7.5 ips)

4.   Settings for playback:

"LINE&PHONES" on: TAPE

"◁◁◁ ▷▷▷" switch in: middle

Channel selector on: 1

Pinch-wheel controlling level: backwards (see Figure D.2 below)
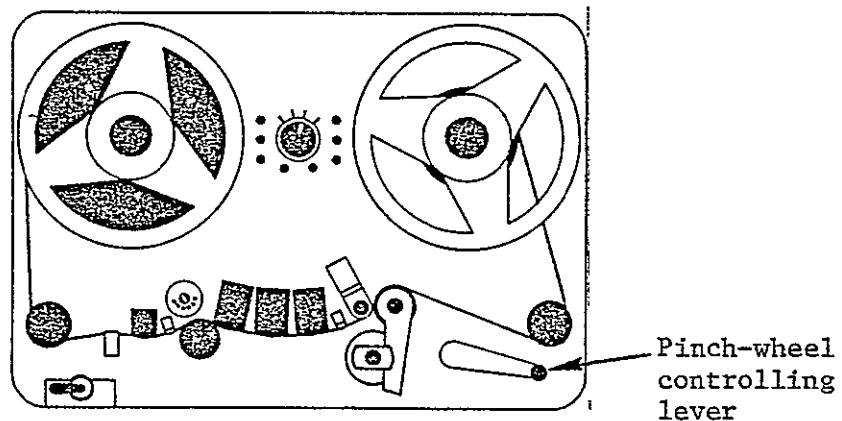

Figure D.2 Top View of Nagra IV Recorder

Tape head cover: closed

Function selector knob on: "PLAYBACK"

5.   Settings for (fast) rewind:

"◁◁◁ ▷▷▷" switch to: left

Pinch-wheel controlling lever: forward

Tape head cover: open

Function selector knob on: "PLAYBACK"

C-15

C.2 Calibration of Equipment

1. Switch on Analyzer, Microphone Power Supply, Equalizer.

2. Connect output of channel 1 (Recorder) to input of Analyzer.

3. Play back the recording of actual noise and write down the Recorder input attenuation specified in the explanation recorded on tape just before the noise recording.

4. Check for Analyzer overloads and adjust Analyzer input attenuation accordingly.

5. Rewind tape.

6. Play back recorded signal and analyze and (linearly) average signal with Analyzer.

7. Transfer analyzed signal to "MEM-2."

8. Connect output of channel 1 (Recorder) with input of Equalizer.

9. Connect output of Microphone Power Supply with input of Analyzer.

10. Set Power Supply switch so as to analyze source microphone.

11. Install a panel and close tube.

12. Switch on Power Amplifier (volume half way).

13. Rewind tape.

14. Play back recorded signal and analyze and (linearly) average signal with analyzer.

15. Compare signals in "MEM 1 & 2."

16. Adjust Equalizer settings to minimize differences between signals in "MEM 1 & 2."

17. Repeat steps 13 through 16 till differences between the two signals have been minimized.

18. Rewind tape to its beginning, where calibration signal is recorded.

19. Play back explanation on tape just before calibration signal and write down the specified Recorder input attenuation setting (during calibration signal).

20. Compute difference between Recorder input attenuations during calibration and actual noise signals.

21. Play back calibration signal and analyze and average (linearly) signal with analyzer.

22. Energize plotter and adjust "Y-ZERO" knob so that pen moves to a level on the graph paper equal to the calibration level corrected for the difference computed in step 20.

C.3 Testing of Panels

1. Rewind tape.

2. Play back noise recording and analyze and (linearly) average signal with Analyzer.

3. Plot result on graph paper using X-Y Plotter.

4. Rewind tape.

5. Change setting of Microphone Power Supply knob to analyze receiver microphone signal.

6. Repeat steps 2 and 3.

4. Manual of HP-9825A Computer Program for Reducing Test Data

1. Turn on calculator and plotter. Switches are located on right and front sides respectively.

2. Insert tape cartridge, label side towards rear of calculator.

3. Type in: trk1;ldf240 and press 'EXECUTE' button. The program, contained on file 240 of track one, is now loaded in calculator memory. The cartridge may be removed.

4. Press 'CHART LOAD' button on plotter. Plotter arm will move to upper right hand corner.

5. Press '4' button on plotter. The arm will pick up the number 4 pen and return to upper right hand corner.

6. If number 4 "pen" is not the sight glass (cursor), then carefully remove the pen from the plotter arm and install the sight glass in the arm. Cap the pen removed.

7. Place raw data plot of source and receiver sound levels in lower left corner of plotter. Press 'CHART HOLD' button and smooth paper. If edges of graph are not parallel to horizontal motion of sight glass/plotter arm (check this by operating the ↑, ↓, →, ← buttons), press 'CHART LOAD,' straighten paper and press 'CHART HOLD' again.

8. Press 'P1' button on plotter. Plotter arm will move to lower left corner.

9. Use the 4-direction buttons (those labeled ↑, →, ↓, ←) to center the sight glass on the intersection point of the botton horizontal grid line (usually 70 dB) and the 20 Hz line. When sight glass is centered hold down the 'ENTER' button while pressing 'P1.' (Both these buttons are on the plotter.)

10. Use the 4-direction buttons to center the sight glass on the intersection of the top grid line (usually 140 dB) and the 500 Hz line. When sight glass is centered, hold down the 'ENTER' button and press 'P2.'

11. Press 'RUN' on calculator.

12. "graph number" will appear on calculator display. Type in the appropriate digit(s) (no letters, e.g. in 12a, are permitted), and press 'CONTINUE.'

13. Display will now read "pressure difference in psi." (Such messages are termed prompts.) Find the correct value on the Data Log sheet (furnished with raw data plots) and type it in. Press 'CONTINUE.'

14. The next prompt requests "source input atten[uation]: 20 - 500 Hz."
    Find this information in the Data Log, type it in, and press
    'CONTINUE.' If no frequency range is stated in the Data Log, the
    value given applies to both low and high frequency ranges (20 - 500
    and 500 - 5000 Hz).

15. Five more prompts will appear, one after another, requesting gain
    and attenuation data. These prompts are:

        "source output gain: 20 - 500 Hz"
        "receiver output gain: 20 - 500 Hz"
        "source input atten: 500 - 5 KHz"
        "source output gain: 500 - 5 KHz"
        "receiver output gain: 500 - 5 KHz"

    In each case, the appropriate value must be found in the Data Log
    and typed in on the calculator keyboard, after which 'CONTINUE'
    must be pressed. Only one value can be entered at a time.

16. For the next prompt, "min[inum] readable level," type in the dB
    level of the lowest point on the receiver curve of the raw data
    plot. The lowest level is usually a flat line between 2000 and
    5000 Hz. To avoid uncertainty in digitizing, pad the lowest level
    by .2 or .3 dB. Thus, if the lowest level is 75.4 dB, type in
    75.7. Press 'CONTINUE.'

17. The calculator will now ask, "Is [the] vert[ical] scale 70 - 140 dB?
    1 = Yes." To answer in the affirmative, press '1,' then press
    'CONTINUE.' To answer in the negative, press any other number, and
    'CONTINUE.'

18. If the answer was negative, the calculator will ask "What is the
    level of the bottom line?" Type in the correct value and press
    'CONTINUE.' "Level of top line?" will be requested next. Type in
    the value and press 'CONTINUE.'

19. Regardless of the answer in step 17, "Source curve: 20 - 500 Hz"
    will now appear on the display, and the sight glass will move to
    the 20 Hz line.

20. Using only the plotter buttons for vertical movement (i.e., '↑' and
    '↓'), position the sight glass center dot exactly on the source
    curve. Then press 'ENTER' button plotter.

21. The sight glass cursor will automatically move a predetermined
    distance to the right. Again move the cursor vertically until it
    is on the curve, and press 'ENTER.' This is called digitizing.

22. Repeat step 21 until calculator beeps (this will happen at about
    the 500 Hz location). Plotter will then move back to the 20 Hz
    line and calculator will display "Receiver curve 20 - 500 Hz."

23. Digitize the low frequency (20 - 500 Hz) part of the receiver
    curve. After last point is digitized, calculator will beep.

24. Similarily, the high frequency (500 – 5000 Hz) source and receiver curves need to be digitized. In response to the "Reenter P1 & P2 for 500 – 5 KHz" prompt, repeat steps 9 and 10 for 500 and 5000 Hz, respectively; then press 'CONTINUE.' Digitize the high frequency durves by the methods of steps 19 – 23.

25. In case of error in digitizing (cursor not on curve when 'ENTER' pressed), press 'STOP,' then 'CONTINUE' on calculator. Cursor should back up to incorrectly digitized location, permitting correct redigitization.

    Occasionally the plotter 'ENTER' button may bounce, causing calculator to read two points instead of one, as cursor moves two steps. If this happens the incorrect second point can be redigitized as if it were a digitizing error.

26. After last point, calculator will beep and display "Ready to plot TL: reenter P1 & P2." Press 'CHART LOAD,' remove raw data plot, and place blank graph paper on plotter table. Locate and hold paper down as described in step 7.

27. Reset P1 and P2 (at lower left and upper right corners) as described in steps 8 to 10.

28. Press 'CONTINUE' on calculator. Plotter will draw the TL curves, label the axes, and number the graph.

29. Press 'CHART LOAD' and remove graph.

30. Calculator will display "To store TL curve on tape, type 1." If you don't want to, type a different number. Then type 'CONTINUE.' Program will end.

31. If you elected to store the curve, the calculator will instruct, "Insert marked, [write-]enabled tape." Do so, and press 'CONTINUE.' Prompts for tape track number (only 0 and 1 are permitted) and file number will then appear. Type each and press 'CONTINUE.' The curve is now stored on tape.

32. Whether you stored the curve or not, the plotter will exchange the pen for the sight glass, in preparation for more data reduction. To reduce more data, press 'RUN' and return to step 4 of this procedure.

    If, however, you would like another plot of the TL curve, load a fresh sheet of semilog paper and reset P1 and P2, as described in steps 26 and 27. Then type: cont76 and press 'EXECUTE.' The plotter will redraw the curve as in step 28, and the calculator will ask about tape storage again.

33. To recall a TL curve from tape storage:

    A) Perform steps 2 and 3, if program is not already present in calculator memory.

B) Type: erase v and press 'EXECUTE.' (This step is only necessary if data, e.g. a TL curve, is already present in calculator memory.)

C) Insert the tape cartridge containing the desired TL curve.

D) Type: cont63 and press 'EXECUTE.'

E) Three prompts will appear successively:

"RECALLING GRAPH No..?"
"TRACK No."
"FILE No."

Respond to each prompt by typing the appropriate digit(s), and pressing 'CONTINUE.'

F) The prompt "Ready to plot TL: reenter P1 and P2" will appear. Respond as in steps 26 - 30.

5. Example of a Specimen Log Sheet

| Company | Date Contacted | Date of Reply | Specimens | | Remarks |
			No.	Type	

C-22

6. Example of a Test Log Sheet

TEST LOG

Date	Graph Number	Panel Number	Panel Type	Panel Treatment	Noise Source	Angle of Incidence	Temperature	Pressure Differential	Source Input Attenuation	Output Gain	Color Coding (Graphs)		Remarks	Operator
											Source	Receiver		

CRINC LABORATORIES

Chemical Engineering Low Temperature Laboratory

Remote Sensing Laboratory

Flight Research Laboratory

Chemical Engineering Heat Transfer Laboratory

Nuclear Engineering Laboratory

Environmental Health Engineering Laboratory

Information Processing Laboratory

Water Resources Institute

Technical Transfer Laboratory

Air Pollution Laboratory

Satellite Applications Laboratory

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