3ND-P&PO-2491

UNCLASSIFIED

TECHNICAL REPORT

U. S. NAVAL APPLIED SCIENCE LABORATORY

NAVAL BASE
BROOKLYN 1, NEW YORK

EACH TRANSMITTAL OF THIS DOCUMENT OUTSIDE THE DEPARTMENT OF DEFENSE MUST HAVE PRIOR APPROVAL OF THE COMMANDER, NAVAL SHIP SYSTEMS COMMAND, WASHINGTON, D. C. 20360

3ND USNASL-9800-P-1A (REV 7-63)

DISCLAIMER NOTICE

REPORT OF DEVELOPMENT

OF

ESTIMATING METHOD FOR

PREDICTING NOISE ORIGINATING IN

AIR CONDITIONING SYSTEMS ON NAVAL VESSELS.

17 AUGUST 1964

(16) SF-013-1109, NASL-Lab. Project 5662-2, Final Report (17) Task 4071

(9) Final rept.,

(10) F. B. HOLGATE, L. D. SHAPIRO, A. SIMOWITZ

Material Sciences Division
D. H. KALLAS, Head

(11) 17 Aug 64

(12) 50p.

Approved: E. J. JEHLE
Technical Director

Approved: I. F. FIKE, CAPT., USN
Commanding Officer and Director

U. S. NAVAL APPLIED SCIENCE LABORATORY
NAVAL BASE
BROOKLYN, NEW YORK 11251

(247 550)

SUMMARY

A method for predicting noise levels, in terms of sound power in octave bands, generated by air conditioning or ventilation systems on submarines and surface vessels has been developed and reported herein.

This method will enable the designer, within certain limitations, to predict system noise prior to construction and where necessary, reduce system noise to specified limits by the use of noise reduction devices.

Lab. Project 5662-2
Final Report

TABLE OF CONTENTS

Lab. Project 5662-2
Final Report

ADMINISTRATIVE INFORMATION

Ref: (a) BUSHIPS ltr F 013 0801, F 013 0803, F 013 1106 Ser 649S-1824, Program Review, of 16 Aug 1960

(b) BUSHIPS ltr NY/3/N26(649S) Ser 649S-3258 of 30 Jul 1958

(c) BUSHIPS ltr S38/3 (549S) Ser 549-5515 of 26 Aug 1954

(d) MATLAB NAVSHIPYDNYK, Project 5662-1, Progress Report 1, NS 713-215, Subtask 18, "A Method for Predicting Octave Band Levels of Ventilation System Noise in Ships' Spaces" of 18 Aug 1955

(e) MATLAB NAVSHIPYDNYK, Project 5662-1, Progress Report 2, NS 713-215, Subtask 18, "Air Conditioning Systems, Estimating Octave Band Levels of Noise" of 26 Sep 1956

(f) MATLAB NAVSHIPYDNYK, Project 5662-1, Progress Report 3, NS 713-215, Subtask 18, "Air Conditioning Systems, Estimating Octave Band Levels of Noise" of 31 Jan 1957

(g) MATLAB NAVSHIPYDNYK, Project 5662-2, Progress Report 1, SF 013 1106, Task No. 4071, "A Method for Estimating Noise Attenuation in Plenums and Intake Boxes" of 16 Feb 1961

(h) MATLAB NAVSHIPYDNYK, Project 5662-2, Progress Report 2, SF 013 1106, Task No. 4071, "A Method for Estimating Noise Attenuation in Fan Intake Boxes" of 3 Jul 1961

(i) MATLAB NAVSHIPYDNYK, Project 5662-2, Progress Report 3, SF 013 1106, Task No. 4071, "A Method for Estimating Noise Attenuation in Fan Intake Boxes" of 20 Sep 1961

(j) NAVAPLSCIENLAB, Project 5662-2, Progress Report 4, SF 013 1106, Task No. 4071, "Noise Attenuation in Plenums Housing a Fan" of 19 Jul 1963

(k) NAVAPLSCIENLAB, Project 5662-2, Technical Memorandum #1, SF 013 1109, Task 4071, "Sound Power Generated by U. S. Navy Vaneaxial and Centrifugal Fans" of 14 May 1964

(l) NAVAPLSCIENLAB, Project 5662-2, Progress Report 5, SF 013 1109, Task 4071, "Generation and Attenuation of Sound Power by Navy Terminals for Air Conditioning Systems" of 23 June 1964

(m) NAVAPLSCIENLAB, Project 5280-30, Technical Memorandum Final Report, SF 013 1101, Task 1357, "Room Constants for Shipboard Compartments" of 18 Nov 1963

(n) General Specifications for Ships of the U. S. Navy

(o) Noise Reduction, edited by L. L. Beranek, McGraw-Hill Book Co., 1960

(p) ASHRAE Progress Report No. 3[illegible], Contract No. 72291, to BUSHIPS for May 1960, dated 13 Jun 1960

(q) ASHRAE Progress Report No. 38, Contract No. 72291, to BUSHIPS for June 1960, dated 15 Jul 1960.

(r) ASHRAE ltr to BUSHIPS (Code 549S) of 19 May 1959 with Final Report on First Phase of Contract No. 72291, "Attenuation and Generation of Sound in Elbows with Turning Vanes" by W. F. Kerka.

(s) Paper "Attenuation of Sound in Lined Ducts With and Without Air Flow" by W. F. Kerka presented at ASHRAE Semi-annual Meeting, Feb 11-14, 1963 (Research sponsored by BUSHIPS).

Lab. Project 5662-2
Final Report

(t) NAVAPLSCIENLAB, Project 5662-3, Technical Memorandum #1, SF 013 1109, Task No. 4071, "Pressure Losses of Fan Intake Boxes" of 12 Nov 1963
(u) NAVAPLSCIENLAB, Project 5662-3, Technical Memorandum, Final Report, SF 013 1109, Task 4071, "Airflow Pressure Losses in Plenums Housing a Fan" of 22 Nov 1963

Encl: (1) Estimating Method for Predicting Octave Band Levels of Ventilation or Air Conditioning System Noise (32 pp)

1. In references (a), (b), and (c) the Bureau of Ships authorized the Naval Applied Science Laboratory (formerly the Material Laboratory) to develop for design purposes a method for estimating noise generated by air conditioning systems. In reference (c), the Laboratory was requested to convert an existing method predicated on overall sound pressure levels to one predicated on sound in octave bands and to conduct necessary laboratory evaluations to obtain required data for all components in air conditioning systems. In reference (b), the Laboratory was requested to enlarge the scope of the work to include attenuation of noise provided by plenums housing fans, and by fan intake boxes. In conferences mentioned in reference (b), it was agreed that the method should be based on sound power levels rather than on sound pressure levels previously used. In reference (a), the Bureau approved continuation of the work under the established Laboratory Project 5662-2.

2. In reference (b)the Bureau requested the Laboratory to experimentally determine airflow pressure loss coefficients for intake boxes and for plenums. This work was reported separately under references (t) and (u) and will not be further discussed herein.

BACKGROUND

3. Air-borne and structure-borne noise generated by air conditioning and ventilation systems on submarines and surface vessels interferes with sonar and communications systems and provides a means for detection by the enemy. Low noise levels are required and the need exists for a realistic method for designing ventilation and air conditioning systems whose noise levels, in octave bands, are within specification requirements. The method should provide means to determine the character and intensity of system noise from drawings so that corrective action, if necessary, can be taken at an early design stage prior to construction. Use of such a method will prevent the need for costly modifications to completed systems where noise levels have been found to be excessive, and will reduce costs by eliminating overdesigned acoustical treatment.

OBJECT

4. The object of this work is to develop a method for estimating noise originating in ventilation or air conditioning systems on submarines and surface vessels. The method is to be suitable for use by designers prior to construction, for predicting noise levels in octave bands in spaces served by the systems.

DESCRIPTION

5. There are two principal types of noise normally encountered in ventilation and air conditioning distribution systems. These two types of noise are briefly described as follows:

a. Fan Noise - This is the type of noise originating in fans and is transmitted through the distribution system. This particular type of noise may be compared to the noise generated by a loudspeaker.

b. Air Flow Noise - This type noise is principally due to air turbulence caused by the windstream passing over system components such as elbows, filters, coils, etc. Although relatively minor, the ducting itself is a source of noise generation at higher air velocities. This is primarily due to boundary turbulence of airflow through the duct.

PROCEDURE

6. The first draft of a method for predicting octave band levels of noise in ventilation systems from design drawings prior to construction of the systems was prepared in a step by step procedure. Authoritative data for generation or attenuation of noise by components were not available but estimates and approximations of sound pressure levels in octave bands were used and were subject to later verification or correction. This first draft of the method was reported in reference (d).

7. Additional sound pressure data were developed for noise generated by centrifugal fans, for noise reduction by exterior duct wrapping and for transmission of fan noise through partitions. These data were reported in reference (e). Additional data for attenuation of airborne noise by sound absorbing duct linings of 1 inch and 2 inch thick fiberglass covered by perforated metal were developed and reported in reference (f).

8. At this point, decision was made to convert the estimating method from a procedure based on sound pressure to one based on sound power. New experimental evaluations of noise generated by Navy fans were made in terms of sound power generated. Principal components of systems were evaluated experimentally to determine the sound power generated by air flow through the components, as well as to determine the sound attenuation or amplification of system noise provided by the component independent of the noise generation effects due to air flow through the component.

9. Fan intake boxes, and plenum chambers housing a fan, were evaluated experimentally to determine sound power generated or attenuated in octave bands by air flow through these components. Principal operating variables included in the investigation were three sizes of intake boxes, three sizes of plenums, three conditions of sound absorbent lining, three sizes and three locations of flow opening, the addition of three types of hoods on the flow opening, and four different air velocities. These investigations were reported in references (g) through (j).

10. Thirteen Navy Standard fans, including eight vaneaxial fans and five centrifugal fans, were experimentally evaluated to determine the sound power in octave bands generated by the fans. This investigation was reported in reference (k).

11. Three types of Navy air distribution terminals were experimentally evaluated to determine the sound power generated in octave bands by the terminals due to air flow through the terminals and to determine the attenuation or amplification of sound generated by fans or by other components elsewhere in the system. The three types were the diffusing terminal, the cone terminal, and the exhaust terminal. The investigation included three sizes of each terminal and three different air velocities. This work was reported in reference (l).

12. Concurrently with the work at the Naval Applied Science Laboratory described above, the American Society of Heating, Refrigerating and Air Conditioning Engineers (ASHRAE) investigated sound power generated by air flow in elbows, in straight unlined ducts, and in straight ducts lined with Navy Standard fiberglas covered by perforated aluminum. This work was done under contract with the Bureau of Ships and was reported in references (p) through (s).

13. The Applied Science Laboratory revised the first draft of the method for predicting noise in ventilation systems which was reported in reference (d). All data for noise generated by fans or by air flow through system components have been expressed in terms of sound power instead of in terms of sound pressure. Approximations of noise attenuated by components and of noise generated by components have been replaced by experimentally determined values of sound power for those components reported in references (k), (l), and (p) through (s). The remaining portion of this report deals with the conversion of the first draft of the method reported in reference (d) to the revised method and coordinated procedure appearing at the end of this report.

14. It is considered that a method for predicting noise levels developed by ventilation and air conditioning systems, in terms of sound power, includes the following necessary elements:

(a) Procedure for the calculation of sound power levels developed by the system and delivered at the openings to the system.

(b) The attenuation and generation characteristics of all the components of the system, in terms of sound power; with and without airflow.

(c) Procedure for determining the acoustic properties of spaces being served by the system.

(d) Procedure for calculating the sound pressure levels at any listening location in the space based on the acoustic properties of the space, the directivity factors of the terminals and the distance between the listener and the noise source.

(e) Allowable noise criteria for various types of spaces.

(f) Procedure for reducing noise levels of systems which are in excess of the allowable noise criteria.

15. The attenuation and generation characteristics of system components were obtained from the available data developed by the Laboratory and other investigative sources. Listed in the tabulation below are the principal components considered and the reference sources of information relative to the acoustical characteristics of the components, with and without airflow.

Component	Reference Source for Noise Attenuation and Generation Characteristics, Without Airflow	Reference Source for Noise Generation Characteristics Due to Air Flow
a. Fans	None	LP 5662-2, Tm #1, ref. (k), enclosures (3), (4)
b. Unlined Duct	ASHRAE ltr-ref.(r) Table 3a	ASHRAE ltr - ref. (p), figures 2, 3 ASHRAE ltr - ref. (q), figure 1
c. Lined Duct	LP 5662-1, Prog. Report 3, ref. (f), figures 1, 2	ASHRAE Paper, ref. (s), figure 10
d. Vaned Elbows	ASHRAE ltr - ref. (r), Table 4a	ASHRAE ltr - ref. (r), figures 11-24, incl.
e. Fan Intake Boxes and Plenums	LP 5662-2 - Prog. Report 3, ref. (i), figure 17* LP 5662-2 - Prog. Report 4, ref. (j), figure 15*	
f. Cooling Coils and Air Filters	LP 5662-1, Prog. Report 1, ref. (d), Table 3	None
g. Heating Coils	LP 5662-1, Prog. Report 1, ref. (d), Table 3	None
h. Terminals	LP 5662-2, Prog. Report 5, ref. (l), Figure 3	LP 5662-2, Prog. Report 5, ref. (l), figures 4, 5, 6
i. Duct Branches	"Noise Reduction" by L. Beranek (McGraw-Hill)	None

* Data were obtained while air was flowing from the fan, and they represent net attenuated fan noise and generated noise due to air flow.

16. The estimated noise levels as reported herein, depend primarily upon an evaluation of sound power levels throughout the duct system. Consequently, acoustical data, referenced in the table above, that were found to be in terms of sound pressure were converted to sound power for purposes of this report. The conversion of sound pressure level to sound power level, where necessary, was based upon fundamental acoustic principles. A brief summary of the modifications for the components listed in the above table, follows:

a. Fans - A tabulation of sound power levels for vaneaxial and centrifugal type fans is given in Table 3 of enclosure (1). This tabulation was obtained from reference (k), enclosures (3), (4) and (5), and includes a reduction of 3 db for each of the sound power levels shown in reference (k). This reduction was necessary since the sound power levels shown in reference (k) represent the combined sound power developed at both the inlet and outlet of the fans, whereas the sound power levels shown on Table 3 (enclosure (1)), represent the sound power levels at either the inlet or outlet of the fans. The sound power levels shown on Table 3 are considered more expedient for calculation purposes.

b. Unlined Ducts - The attenuations provided by unlined ducts in terms of sound pressure were evaluated in reference (r), Table 3a, for various duct sizes and aspect ratios. In view of the relative uniformity of the tabulated attenuation factors, average attenuations per foot were calculated which were considered to be representative for all duct sizes and aspect ratios in any given octave band. These average attenuation factors are also applicable for sound power level attenuation and are noted in Table 4 of enclosure (1). Sound pressure levels generated by various air velocities in three different square sizes of unlined ducts were reported in reference (p), Figures 2 and 3, and in reference (q), Figure 1. These sound pressure levels were converted to sound power levels and are shown in Figure 4 of enclosure (1). The conversion from sound pressure level to sound power level was accomplished by use of the following relationship given in reference (o), Page 179:

$$PWL = SPL_d + 10 \log_{10} S_d$$

where

PWL = sound power level, db re 10^{-13} watt

SPL_d = mean-square sound pressure level, db re 0.0002 microbars, obtained over cross-sectional area S_d of duct, ft^2

c. Lined Ducts - Attenuations, in decibels, provided by ducts of various perimeter-cross sectional area ratios and lined with 1" and 2" thick sound absorbent lining (MIL-I-15365B) under perforated aluminum, without airflow, were reported in reference (f), Figures 1 and 2. Since decibel attenuation is identical in both sound pressure level and sound power level work, Figures 10 and 11, reported herein, are similar to Figures 1 and 2, reference (f). Sound pressure levels generated by various air velocities through a 12" x 12" duct lined with a 1" thick lining, described above, were reported in reference (s), Figure 10. In a manner similar to that used for unlined ducts, sound pressure levels were converted to sound power levels, and are shown on Figure 12 of enclosure (1). In completing Figure 12, it was assumed that the sound power levels generated with airflow on a 2" thick lining are the same as for a 1" thick lining. It was also assumed that the differences in sound power level between different sizes of ducts will be the same in lined duct as in unlined duct.

d. Vaned Elbows - The data for vaned elbows, presented in reference (r), Table 4a, represent attenuations in sound pressure levels, without airflow, for different sizes, aspect ratios and angles of bend. In view of the relative uniformity of the data, average attenuations were calculated which are considered representative of the three parameters. These attenuations, which are again applicable in sound power work, are included in Table 4 of enclosure (1). Sound pressure levels generated by various air velocities through unlined vaned elbows of different sizes, aspect ratios and angles of bend are shown in reference (r), Figures 11 through 24. Again, as previously described, average sound power levels of vaned elbows were determined and are graphically shown in Figure 5 of enclosure (1).

e. Other Elbows - It was assumed that sound power level data for elbows other than vaned, with and without airflow, are the same as that for vaned elbows, and are shown on Table 4 and Figure 5, respectively, in enclosure (1).

f. Intake Boxes and Plenums - Sound power attenuation provided by lined intake boxes and plenums have been reported in reference (i), Figure 17 and reference (j), Figure 15. Graphical representation of these sound power attenuation characteristics are included in enclosure (1) as Figures 13 and 14, respectively. Figures 13 and 14 are predicated on the assumption that the sound absorption coefficients of lining materials meeting the requirements of MIL-I-15365 will be similar to those shown for Owens-Corning PF-334 in reference (j).

g. Cooling Coils and Air Filters - Attenuations provided by cooling coils and air filters, without airflow, were reported in reference (d), Table 3, and are included in Table 4 of enclosure (1).

h. Heating Coils - Attenuation data, provided by heating coils, were likewise reported in reference (d), Table 3 and are also included in Table 4 of enclosure (1).

i. Terminals - Sound power level attenuation and generation characteristics of three Navy type terminals, with and without airflow, were reported in reference (1), Figures 3, 4, 5 and 6 and are included in enclosure (1) as Figures 6, 7, 8 and 9.

j. Duct Branches - Sound energy, traveling along a main duct, divides on an energy basis when reaching a junction of two or more branches. The reduction in sound power level from a main duct to a branch duct is based on the following relationship developed from a formula given in reference (o), page 556:

$$PWL\ (Branch) = PWL\ (Duct) - 10 \log_{10} \frac{A_t}{A_d},$$

where:

PWL (Branch) = Sound power level in particular branch
PWL (Duct) = Sound power level in main duct at branch point
A_t = Total cross section area of all branch ducts leaving junction

A_d = Cross section area of particular branch

Figure 3 of enclosure (1) shows a graphical means by which the sound power level reduction between a main duct and a branch duct can be determined.

17. The acoustic properties of spaces being served by a system become relevant factors in translating the sound power levels at the face of a terminal to sound pressure levels at a listener or working station. Values for room constant were obtained by use of the following relationship given in reference (o), page 237:

$$R = \frac{S\bar{\alpha}}{1-\bar{\alpha}},$$

where:

R = Room constant, in sq. ft.
$\bar{\alpha}$ = Average sound absorption coefficient
S = Total surface area, in sq. ft.

Figure 1 of enclosure (1) was developed using the above relationship and it provides for designers a means for estimating the Room Constant of a space as a function of the six boundary surface areas and the average sound absorption coefficients of the space contents, in octave bands. Data for Room Constants were obtained from results reported in reference (m) for spaces of known "Noise Category" aboard the EAG 153, USS COMPASS ISLAND. Additional data were also obtained for the Ventilation Acoustic Chamber in the Laboratory, which was considered analagous to a Noise Category "C" type of space. For compactness, a tabulation of sound absorption coefficients for spaces of different "Noise Categories" is also shown in Figure 1 of enclosure (1).

18. The procedure for determining the sound pressure levels at any listening location in a space based on the acoustic properties of the space, the directivity factors of the terminals, and the distance between the listener and the noise source was developed from the expression:

$$SPL-PWL = -\left[10 \log \left(\frac{Q}{2\pi r^2} + \frac{4}{R}\right)\right]$$

where:

PWL = Sound power level at terminal (db - re 10^{-13} watt)

SPL = Sound pressure level at listening location (db - re 0.0002 microbars)

r = Distance between face of terminal and listening location, in feet

R = Room constant of space (sq. ft.)

Q = Directivity factor of terminal

For purposes of expediency, an average directivity factor of Q=2 was assumed for all terminals. Figure 2 of enclosure (1) shows in graphical form the relationships developed from the above expression.

19. Allowable noise criteria for various types of spaces are given in Section S1-10 of the general Specifications for Ships of the U. S. Navy. For noise categories A or E where Speech Interference Levels (SIL) are specified, a distribution of allowable levels was assumed in the four octave bands from 300 cps to 4800 cps. The distribution was based on descending 4 db per octave band with ascending frequency, and with the average of the four octave band levels equal to the SIL specified. The distribution of allowable levels for SIL Categories A and E are shown in Table 1 of enclosure (1).

RESULTS

20. An estimating method for predicting octave band levels of ventilation or air conditioning system noise is presented in enclosure (1) herewith, which includes four tables and fifteen figures. Table 1 provides a step by step procedure of the method and includes:

a. Setting up of the problem based on a specific system.

b. The determination of the maximum allowable sound pressure levels of spaces served by the system.

c. The method for calculating the sound power levels delivered by the system at the terminals.

d. The determination of the acoustical characteristics of the spaces served by the system.

e. The determination of the sound pressure levels at the working stations of a space resulting from the sound power levels at the terminals in the space.

f. The determination of the attenuation required in a system where sound pressure levels at the working stations exceed specification requirements.

g. Design of sound absorbing duct work, fan intake boxes, or plenum housing the fan, to provide the attenuation requirements.

21. Table 2 is a sound control work sheet which is used to implement the step by step procedure described in Table 1. Incorporated in Table 2 is an example, in one octave band, of the application of the method for a typical air conditioning system.

22. The calculation of the sound power levels delivered by a system at the terminals can be accomplished as indicated in Step III of Table 2. Supporting experimental and estimated data relative to the sound power level attenuation and generation characteristics of system components are shown on Tables 3 and 4, and Figures 3 through 9 and 15.

23. Figure 1 provides a means by which the acoustical characteristic, room constant R, of spaces served by a system can be determined. In conjunction with results obtained from Figure 1, Figure 2 provides the means by which the difference between the sound power levels at the terminals and the sound pressure levels at the working stations can be determined, which in turn is used to establish the sound pressure levels at the working stations. A comparison between the sound pressure levels at the working stations and those permitted in the space by reference (n), indicates the octave bands in which reductions in sound pressure levels are necessary to meet specifications. Figures 10 through 14 provide the means for obtaining the necessary noise reduction in the system.

CONCLUSIONS

24. It is concluded that:

a. Enclosure (1), with Tables 1 through 4 and Figures 1 through 15 provides for ventilation and air conditioning systems:

(1) A suitable method for estimating noise developed by such systems on a sound power basis.

(2) A procedure for translating sound power delivered at the terminals of such systems to sound pressure levels that will exist and can be measured at various locations in a room.

(3) A means by which noise levels developed by these systems can be reduced by relocation of terminals, by the acoustical treatment of duct work, or by the use of acoustically lined intake boxes and plenums housing a fan.

b. The revised noise estimating method shown in enclosure (1) provides the following advantages over the first draft of the method, reference (d):

(1) A noise estimating method based on sound power, a fixed acoustical characteristic, provides a fundamental and more desirable basis for estimating and comparing ventilation and air conditioning systems and system components than one based on room sound pressure levels.

(2) Experimental data are used in lieu of estimated data for many system components.

RECOMMENDATIONS

25. It is recommended that the method for estimating octave band levels of noise reported in enclosure (1), be distributed for use by Naval designers. It is suggested that the design agencies report to the Bureau, the extent of agreement found between the noise levels predicted by the method and those found by actual measurement in completed systems.

FUTURE WORK

26. The U. S. Naval Applied Science Laboratory has no plans for continuing work on this project after June 1964. This is a final report.

27. While experimental data for generation and attenuation of noise by the principal generators and attenuators among system components have been obtained and integrated into the procedure reported herein, consideration should be given to obtaining similar experimental data for the following system components: heating and cooling coils including their duct transformations, branch take-offs, elbows other than vaned elbows, flame arresters, watertight closures, silencers and mufflers.

28. Attenuation in 12" x 12" straight ducts lined with one inch thick fiberglass covered by perforated metal was measured as part of the work reported by ASHRAE in reference (s). Consideration should be given to experimental determination of attenuation for other sizes and other aspect ratios of duct, and for two inch thick linings.

ESTIMATING METHOD
FOR PREDICTING OCTAVE BAND LEVELS OF
VENTILATION OR AIR CONDITIONING SYSTEM NOISE

U. S. NAVAL APPLIED SCIENCE LABORATORY
NAVAL BASE
BROOKLYN, NEW YORK 11251

ESTIMATING METHOD

FOR PREDICTING OCTAVE BAND LEVELS OF

VENTILATION OR AIR CONDITIONING SYSTEM NOISE

Tables 1 through 4, and Figures 1 through 15 form a package which contains all information necessary for using and applying the estimating method. Table 1 outlines the procedure and refers to item numbers on Table 2 which is a suggested work sheet on which a typical example has been worked out. Tables 3 and 4, and Figures 1 through 15 contain data used in the various steps of the procedure.

Tables:

1. - Procedure for Prediction of Octave Band Levels of System Noise.

2. - Sample Sound Control Work Sheet and Example for Predicting Noise Levels.

3. - Sound Power Levels at Either Inlet or Outlet of Navy Standard Fans.

4. - Sound Power Level Attenuation of System Components without Airflow.

Figures:

1. Design Curves for Estimating the Room Constant (R) of a Space as a Function of the Surface Area of the Space and the Average Sound Absorption Coefficient (α).

2. Design Curves for Predicting the Sound Pressure Levels in a Space as a Function of the Room Constant (R) and the Distances from the Noise Source to Listener.

3. Reduction in Sound Power Level from a Main Duct to a Branch Duct.

4. Sound Power Level Generated in Octave Bands Due to Airflow in Straight Ducts with No Lining, for Any Length of Duct.

5. Sound Power Level Generated in Octave Bands Due to Airflow in Vaned Elbows of Any Angle of Bend, with No Lining.

6. Sound Power Level Attenuation or Generation Characteristics of Navy Standard Diffuser, Exhaust, and Cone Type Terminals (Without Airflow).

7. Average Sound Power Levels of Navy Standard Cone Terminals, Due to Airflow.

8. Average Sound Power Levels of Navy Standard Exhaust Terminals, Due to Airflow.

9. Average Sound Power Levels of Navy Standard Diffuser Terminals, Due to Airflow.

10. Sound Power Level Attenuation in Octave Bands in Straight Ducts Lined on Four Sides with 1" thick Navy Standard Fiberglass and Perforated Aluminum, No Airflow.

11. Sound Power Level Attenuation in Octave Bands, in Straight Ducts Lined on Four Sides with 2" thick Navy Standard Fiberglass and Perforated Aluminum, No Airflow.

12. Sound Power Level Generated in Octave Bands Due to Airflow in Straight Ducts Lined 1" or 2" thick Navy Standard Fiberglass and Perforated Aluminum, for Any Length of Duct.

13. Design Curves for Predicting Sound Power Level Attenuation of Rectangular Intake Boxes (Without Internal Baffles and Lined with Navy Standard Fiberglass and Perforated Aluminum) as a Function of Sound Absorption Coefficient (α) and Total Internal Surface Area.

14. Design Curves for Predicting Sound Power Level Attenuation of Rectangular Plenums Housing a Fan (Without Internal Baffles and Lined with Navy Standard Fiberglass and Perforated Aluminum) as a Function of Sound Absorption Coefficient (α) and Total Internal Surface Area.

15. Chart for Combining Noise Levels.

TABLE 1

PROCEDURE FOR PREDICTING OCTAVE BAND LEVELS OF SYSTEM NOISE

Step I

Identifying Information

a. Enter information indicated in items 1, 2, 3 on Table 2.

b. In Item 4, draw a single line diagram of entire system, showing all duct work and components. Letter and number the junction points of the system to separate mains, branch-mains and branches. Show all spaces in which there are inlet or discharge openings for the system, hereafter referred to as terminals. Show space dimensions. Indicate air velocities in fpm; duct lengths in feet; and the sizes of all ducts and system components.

c. In Item 5, enter the information indicated, including the distance from each terminal to the nearest listener (nearest working station).

d. In Item 6, enter the information indicated, for each space served by the system.

Step II

Maximum Allowable Sound Pressure Levels in Space

a. In item 7, enter the designation for noise category of each space. Select category from Section S28-3-c of General Specifications for Ships of the United States Navy.

b. For noise categories B, C, or D, select from Section S1-10-c of General Specifications the allowable sound pressure levels in each octave band and enter them in Item 8. Use space volume, item 6, when making selection.

c. For noise categories A or E where speech interference levels (SIL) are specified, assume distribution of allowable levels in the octave bands as follows:

ALLOWABLE SOUND PRESSURE LEVEL, db

Noise Category	Vol. of Room (cu. ft.)	SIL	Octave Bands, cps 300–600	600–1200	1200–2400	2400–4800
A	500 to 1999	60	66	62	58	54
	2000 to 7999	55	61	57	53	49
	8000 or larger	50	56	52	48	44
B	any	72	78	74	70	66

Select allowable levels in four octave bands from appropriate line in tabulation above and enter them in item 8.

d. If other important noise sources are present in the space, which are likely to produce noise levels equal to those created by the air conditioning system, deduct 3 db from the levels selected under (b) or (c) before entering them in item 8.

Step III

Calculation of Predicted Noise Developed by System

a. In items 9 and 10, enter data indicated.

b. For purposes of calculation, the fan is considered the start of the system and the sound power levels at the terminals are to be computed independently from the discharge side of the fan to each discharge terminal and from the intake side of the fan to the intake of the system. From the fan, and for either the upstream or downstream side of the system, the available sound power level attenuation and generation data of all system components, under both airflow and no flow conditions, are to be integrated into the calculation in consecutive order until the sound power level at the face of the intake or terminal opening to the system is determined.

c. All available data for the calculation are given on Tables 3 and 4, and Figures 1 through 9 and 13 through 15. Data for sizes of components other than given in the aforementioned tables and figures are to be obtained by interpolation. Data for configurations of components other than those given in the aforementioned tables and figures are to be obtained by choosing from the given components, one closely resembling the component in question. Where data are not available for either the airflow or no flow condition of the given component, it is to be assumed that these acoustical characteristics are not pertinent to the calculation and shall be omitted.

d. By way of example, and for purposes of explanation and clarity, the steps in the calculation for one octave band are shown in item 11 of Table 2 for the system as shown in item 4. This procedure should also be applied to all other octave bands in the frequency range of 75 cps through 9600 cps.

Step IV

Determination of Necessary Attenuation

a. Necessary attenuation in each octave band is the number of decibels by which the calculated sound pressure levels at the listener, determined in column 10 of Table 2, exceeds the maximum allowable levels in the same octave bands as shown in Item 8. In the tabulation, item 12, Table 2, enter the data indicated.

Step V

Obtaining the Necessary Attenuation

a. Determine from Figure 2, if the necessary attenuation can be obtained by increasing the distance between the terminal, or the fan inlet, and the listener at the work station. If feasible, select new location of terminal or fan inlet and show it in item.13.

b. If a terminal cannot be moved to obtain the necessary attenuation, use Figure 10 or 11 to determine the minimum length of sound absorbing lined duct which is required to reduce each octave band level to the maximum allowable sound pressure level in the space. Use the longest length required by any of the several octave bands. If the required length of lined duct exceeds the length of duct in the branch, sub-divide the duct into cells with duct lining to provide greater attenuation in a given length. The amount of noise reduction attainable by sound absorbing duct lining:

1. Is limited to a maximum attenuation of 25 db.
2. Is limited by the generated sound pressure level of the terminal (column 7 minus column 9 in item 11).
3. Is limited by generated sound pressure level of lined duct work. (PWL from Figure 12 minus column 9 in item 11).
4. Show calculations in item 14.

c. .. the fan inlet cannot be moved to obtain the necessary attenuation, select an intake box to be installed on the fan inlet, or a plenum to be installed around the fan, by use of Figure 13 or 14. Use a box or plenum having the largest lining area required by any octave band. Show calculation in item 15. Provide an air inlet opening to the box having an area from 1.0 to 1.5 times the face area of the bellmouth on the fan. Show calculation in item 16.

TABLE 2

SAMPLE SOUND CONTROL WORK SHEET

AND EXAMPLE FOR PREDICTING NOISE LEVELS

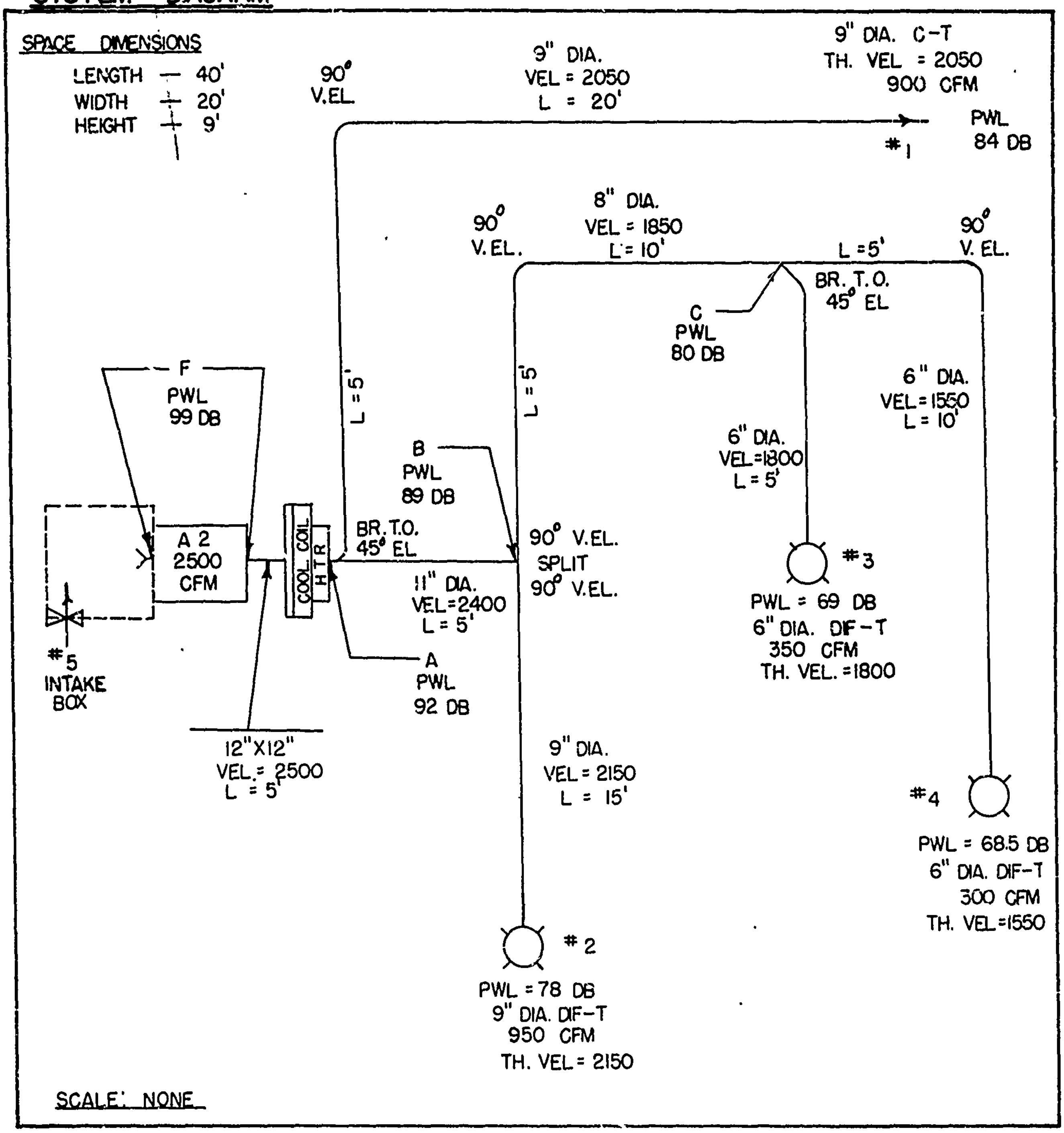
Step 1

Identifying Information

Item Number		
1	Name and number of vessel: System number:	
2	Type and size of fan:	Vaneaxial, A2
3	Name of space served: Number of space served:	
4	System diagram: (see next page)	

TABLE 2 (SHEET 2)

SYSTEM DIAGRAM



LEGEND:

VEL. — VELOCITY OF AIR IN FPM
TH. VEL. — THROAT VELOCITY OF AIR IN FPM
PWL — SOUND POWER LEVEL, IN DB
SPL — SOUND PRESSURE LEVEL, IN DB
DIF – T — DIFFUSION TERMINAL
C-T — CONE TERMINAL
L — LENGTH OF DUCT, IN FT.
V. EL — VANED ELBOW
EL — ELBOW
BR. T.O. — BRANCH TAKEOFF

Item
Number

5 Terminal Data:

Terminal No. on Diagram	Type	Size	Distance to Listener
#1	Cone	9" Dia.	5'
#2	Diffusing	9" Dia.	8'
#3	Diffusing	6" Dia.	10'
#4	Diffusing	6" Dia.	15'
#5	Intake Box	-	10'

6. Space Dimensions:

Length	40'
Width	20'
Height	9'
Surface area of space (6 boundaries), in sq. ft.	2680
Volume of space, in cu. ft.	7200

Step II

Maximum Allowable Sound Pressure Levels in Space

7. Space Noise Category:

See Section 28-3-c, General Specifications
Category "C" (assumed for example)

8. Maximum Allowable Sound Pressure Levels in Space at Listeners:

See Section S1-10, General Specifications

	Octave Pass Bands, cps						
	75 150	150 300	300 600	600 1200	1200 2400	2400 4800	4800 9600
Max. SPL, db	72	68	64	60	56	52	48

Item
Number

Step III

Calculation of Predicted Noise Developed by System

9. Room Constants "R" for Spaces Served:

Noise category of space: "C"
Total surface area: 2680 sq. ft.

From Figure 1:

	Octave Pass Bands, cps						
	75 150	150 300	300 600	600 1200	1200 2400	2400 4800	4800 9600
"R"				1150			

10. Difference between PWL at Terminals and SPL at Listener, in db (from items 5, 9, and Figure 2):

		Octave Pass Bands, cps						
Terminal	Distance to Listener	75 150	150 300	300 600	600 1200	1200 2400	2400 4800	4800 9600
#1	5'				20.0			
#2	8'				22.0			
#3	10'				22.5			
#4	15'				24.0			
#5	10'				22.5			

Item Number 11.

Calculation of Predicted Noise Developed by System for
Octave Band: 600 to 1200 cps

1	2	3	4	5	6	7	8	9	10
System Diagram Section	PWL at Start of System Component, db	Duct System Component	Attenuation in Component, db	Attenuated PWL, db	Air Vel. thru Component, fpm	Generated PWL, db	PWL at End of System Component, db*	Diff. bet. PWL at Term and SPL at Listener	SPL at Listener, db
FA	99	Duct (12"x12")	0.5	98.5	2500	60	98.5	---------	---------
	98.5	Cool Coil	4.5	94.0	-----	---	94.0	---------	---------
	94	Htr.	2.0	92.0	-----	---	92.0	---------	---------
AB	92	Br. T.O.	2.5	89.5	-----	--	89.5	---------	---------
	89.5	Duct (11")	0.5	89.0	2400	56	89.0	---------	---------
BC	89	Br. T.O.	3.5	85.5	-----	--	85.5	---------	---------
	85.5	45° El.	2.0	83.5	1850	54	83.5	---------	---------
	83.5	Duct (8")	0.5	83.0	1850	46	83.0	---------	---------
	83	V. El.	2.0	81.0	1850	54	81.0	---------	---------
	81	Duct (8")	1.0	80.0	1850	46	80.0	---------	---------
C4	80	Br. T.O.	3.0	77.0	-----	--	77.0	---------	---------
	77	Duct (6")	0.5	76.5	1550	34	76.5	---------	---------
	76.5	V. El.	2.0	74.5	1550	44	74.5	---------	---------
	74.5	Duct (6")	1.0	73.5	1550	34	73.5	---------	---------
	73.5	Dif. T (6")	5.0	68.5	1550	58	68.5	24.0	44.5
C3	80	Br. T.O.	3.0	77.0	-----	--	77.0	---------	---------
	77	45° El.	2.0	75.0	1800	48	75.0	---------	---------
	75	Duct (6")	1.0	74.0	1800	37	74.0	---------	---------
	74	Dif. T (6")	5.0	69.0	1800	59	69.0	22.5	46.5

Item
Number
11.

Calculation of Predicted Noise Developed by System for
Octave Band: 600 to 1200 cps
(Cont'd)

1	2	3	4	5	6	7	8	9	10
System Diagram Section	PWL at Start of System Component, db	Duct System Component	Attenuation in Component, db	Attenuated PWL, db	Air Vel. thru Component, fpm	Generated PWL, db	PWL at End of System Component, db*	Diff. bet. PWL at Term and SPL at Listener	SPL at Listener, db
B2	89	Br. T.O.	2.5	86.5	----	--	86.5	--------	--------
	86.5	V. El.	2.0	84.5	2150	58	84.5	--------	--------
	84.5	Duct (9")	1.5	83.0	2150	50	83.0	--------	--------
	83	Dif. T (9")	5.0	78.0	2150	63	78.0	22.0	56.0
A1	92	Br. T.O.	4.0	88.0	----	--	88.0	--------	--------
	88	45° El.	2.0	86.0	2050	58	86.0	--------	--------
	86	Duct (9")	1.0	85.0	2050	48	85.0	--------	--------
	85	V. El.	2.0	83.0	2050	58	83.0	--------	--------
	83	Duct (9")	2.0	81.0	2050	48	81.0	--------	--------
	81	C-T (9")	- 3.0	84.0	2050	60	84.0	20.0	64.0
F5	99	Fan Inlet	(Assuming no intake box)				99.0	22.5	76.5

* Logarithmic addition of Col. 5 and Col. 7 using Figure 15.

Item
Number

Step IV

Determination of Necessary Attenuation

12. Necessary Attenuation, in decibels:

	Octave Bands: cps						
	75 150	150 300	300 600	600 1200	1200 2400	2400 4800	4800 9600
Maximum Allowable SPL at Listener →	72	68	64	60	56	52	48
Section A1, SPL* Nec. Atten.				64.0 4.0			
Section B2, SPL* Nec. Atten.				56.0 None			
Section C3, SPL* Nec. Atten.				46.5 None			
Section C4, SPL* Nec. Atten.				44.5 None			
Section F5, SPL* Nec. Atten.				76.5 16.5			

* SPL at listener from column 10 Item 11.

Item
Number

Step 7

Obtaining the Necessary Attenuation

13. Move terminal No. _____ to _________.
Move fan inlet to _________.

14. Length of lined duct required:

Section A1, 1" thick lining, octave band 600-1200;
P/A ratio = .44; Attenuation = 3.0 db per ft. of duct (from Figure 10);
Lined duct required = 4.0 ÷ 3.1 = 1.3 feet for octave band 600-1200.
(Calculate length required for each of the other octave bands).

15. Selection of intake box for fan:

On Figure 13, select 1" thick lining. Coefficient α = 0.69 for octave band 600-1200. For 16.5 db necessary attenuation and α = 0.69, the internal surface area of lined intake box must be 46.5 s.f. for octave band 600-1200. Calculate area required for each of the other octave bands.

16. Selection of air inlet opening to intake box:

Face area of bellmouth for A2 fan = 2.16 s.f.
Area of opening in intake box = 1.25 x 2.16 = 2.7 s.f.

TABLE 3

SOUND POWER LEVEL AT EITHER INLET OR OUTLET

OF NAVY STANDARD FANS
DB - RE 10^{-13} WATTS

Fan Type	Std. Fan	Navy Size	Octave Pass Bands, cps						
			75 150	150 300	300 600	600 1200	1200 2400	2400 4800	4800 9600
Vaneaxial	A	1/4	79	97	93	89	87	82	77
"	A	1/2	69	80	88	89	89	85	78
"	A	1	73	85	87	86	88	85	77
"	A	1 1/2	76	88	95	98	99	93	86
"	A	2	84	93	96	99	98	91	90
"	A	3	84	91	89	88	87	83	77
"	A	4	88	98	99	94	93	86	83
"	A	6	92	101	101	100	95	86	80
Centrifugal	C	1/4	86	100	88	83	82	75	68
"	CC	1/2	89	90	88	85	83	77	71
"	CC	2	94	92	92	90	94	85	77
"	CC	3	98	91	93	90	93	90	79
"	CC	5	104	95	97	95	98	92	84

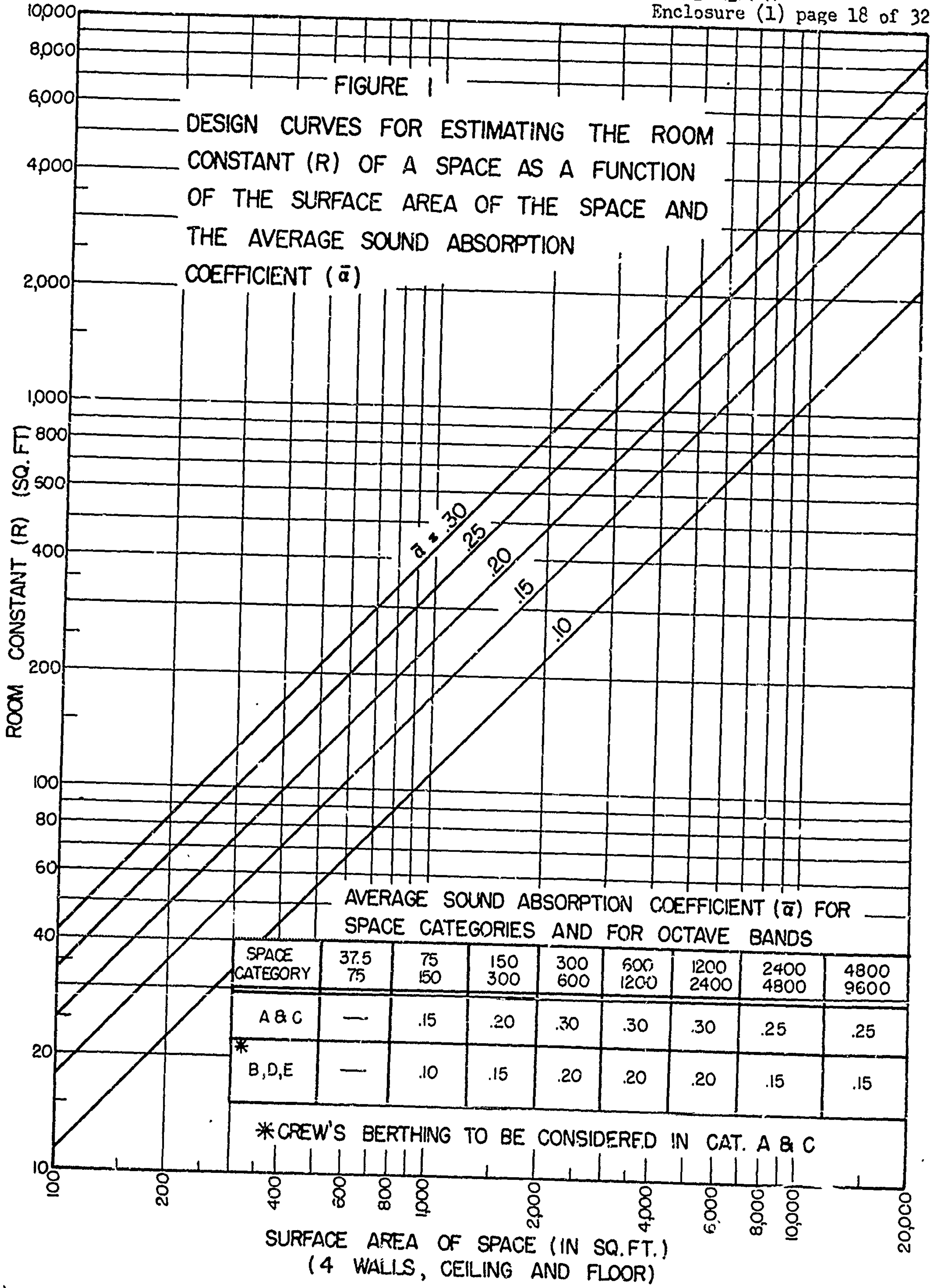
TABLE 4

SOUND POWER LEVEL ATTENUATION OF SYSTEM COMPONENTS

WITHOUT AIR FLOW, DECIBELS

Component	Octave Pass Bands, cps						
	75 150	150 300	300 600	600 1200	1200 2400	2400 4800	4800 9600
Cooling Coil & Air Filter	0.5	1.5	3	4.5	5.5	7.5	8.5
Heating Coil	0.5	1	1.5	2.0	2.5	3.0	3.5
Unlined Duct, db per ft.	0.22	0.16	.20	.10	.12	.15	.18
Vaned Elbows	0	2	2	2	2	3	3
Other Elbows (Estimated)	0	2	2	2	2	3	3
Lined Duct	Shown in Figures 10 and 11						
Intake Boxes & Plenums	Shown in Figures 13 and 14*						
Navy Terminals	Shown in Figure 6						
Duct Branches	Shown in Figure 3						

* Data were obtained while air was flowing from the fan, and they represent net attenuated fan noise and generated noise due to air flow.

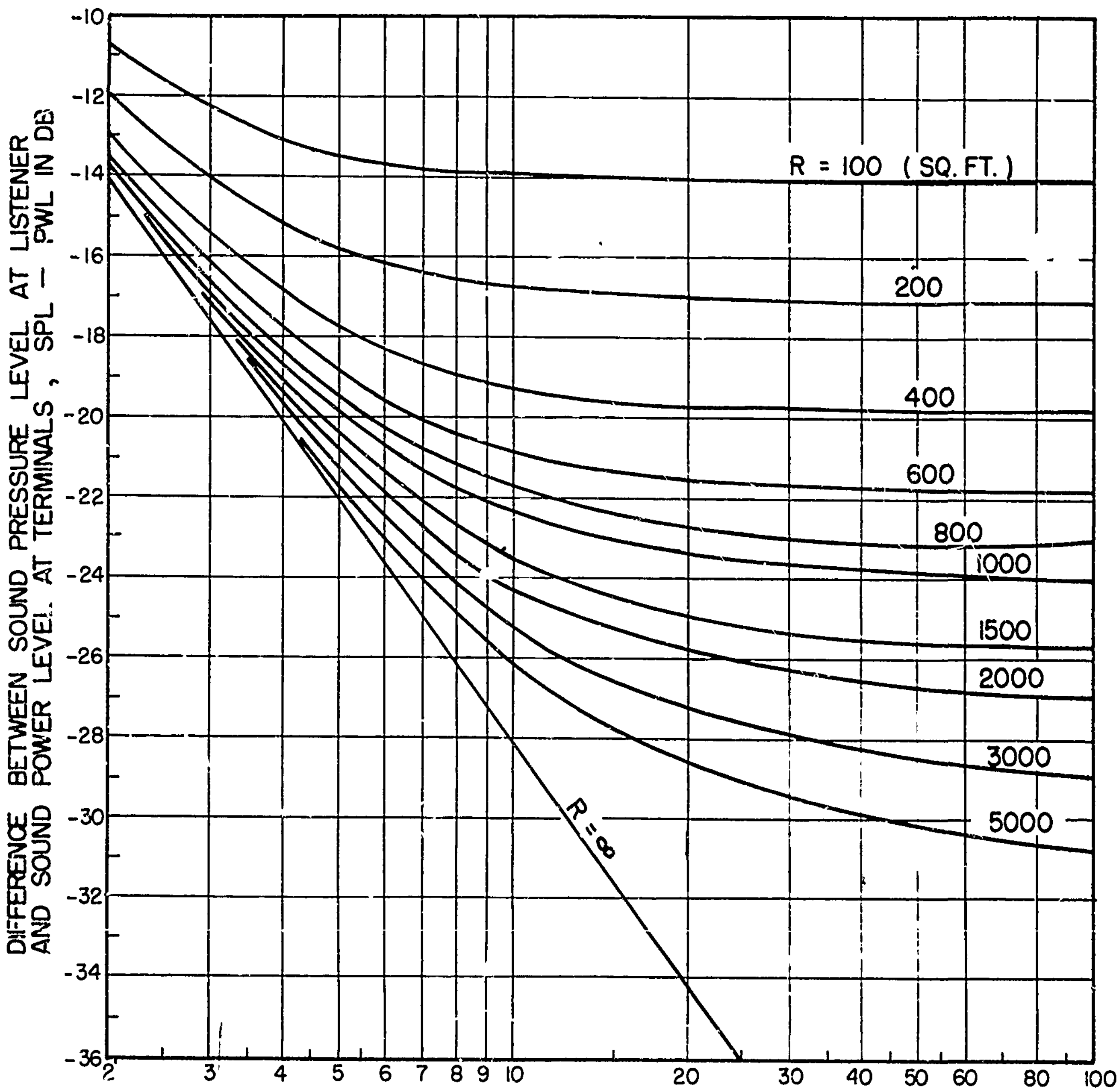


SPACE CATEGORY	37.5 75	75 150	150 300	300 600	600 1200	1200 2400	2400 4800	4800 9600
A & C	—	.15	.20	.30	.30	.30	.25	.25
* B, D, E	—	.10	.15	.20	.20	.20	.15	.15

*CREW'S BERTHING TO BE CONSIDERED IN CAT. A & C

FIGURE 2

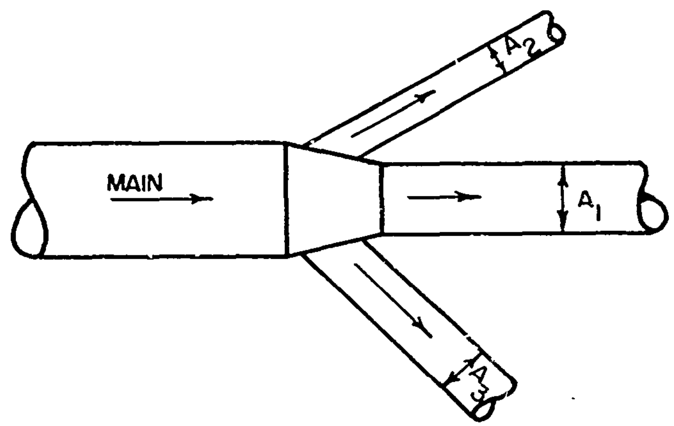
DESIGN CURVES FOR PREDICTING THE SOUND PRESSURE LEVELS IN A SPACE AS A FUNCTION OF THE ROOM CONSTANT (R) AND THE DISTANCE FROM THE NOISE SOURCE TO LISTENER

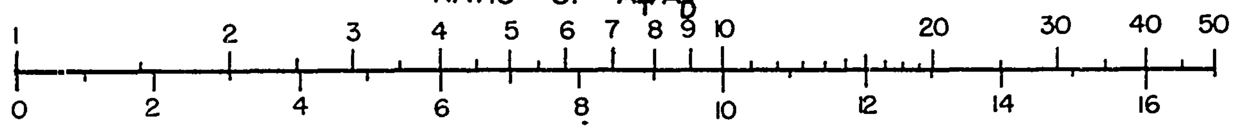


DISTANCE FROM NOISE SOURCE TO LISTENER, IN FEET

FIGURE 3

REDUCTION IN SOUND POWER LEVEL FROM A MAIN DUCT TO A BRANCH DUCT





$A_T = A_1 + A_2 + A_3$; TOTAL CROSS SECTIONAL AREA OF ALL BRANCHES LEAVING JUNCTION.

$A_D = A_1$, OR A_2, OR A_3; CROSS SECTIONAL AREA OF BRANCH DUCT IN QUESTION.

FIGURE 4

SOUND POWER LEVEL GENERATED IN OCTAVE BANDS DUE TO AIRFLOW IN STRAIGHT DUCTS WITH NO LINING, FOR ANY LENGTH OF DUCT

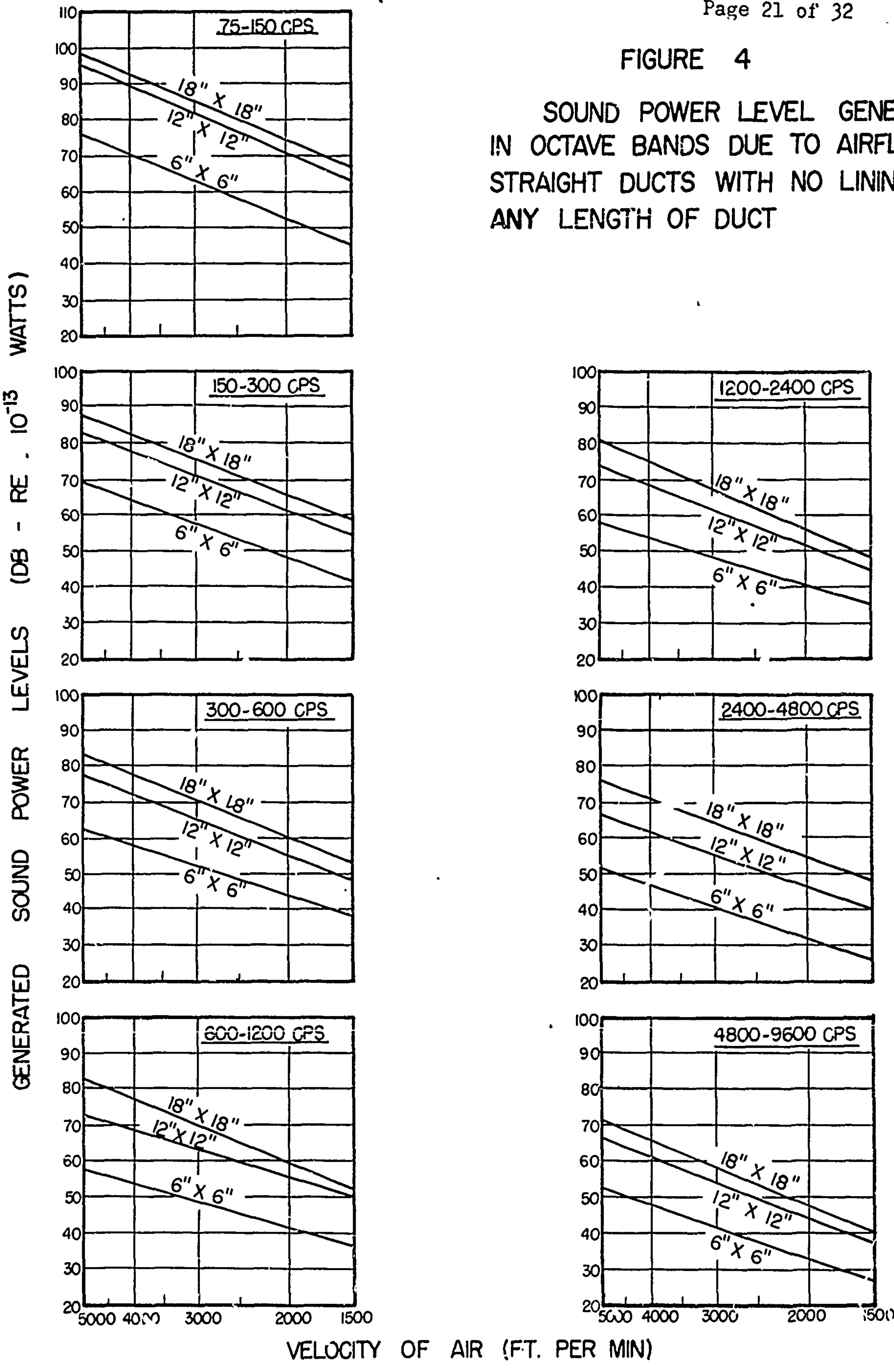


FIGURE 5

SOUND POWER LEVEL GENERATED IN OCTAVE BANDS DUE TO AIRFLOW IN VANED ELBOWS OF ANY ANGLE OF BEND, WITH NO LINING

NOTE: USE THESE DATA ALSO FOR ELBOWS WITHOUT VANES

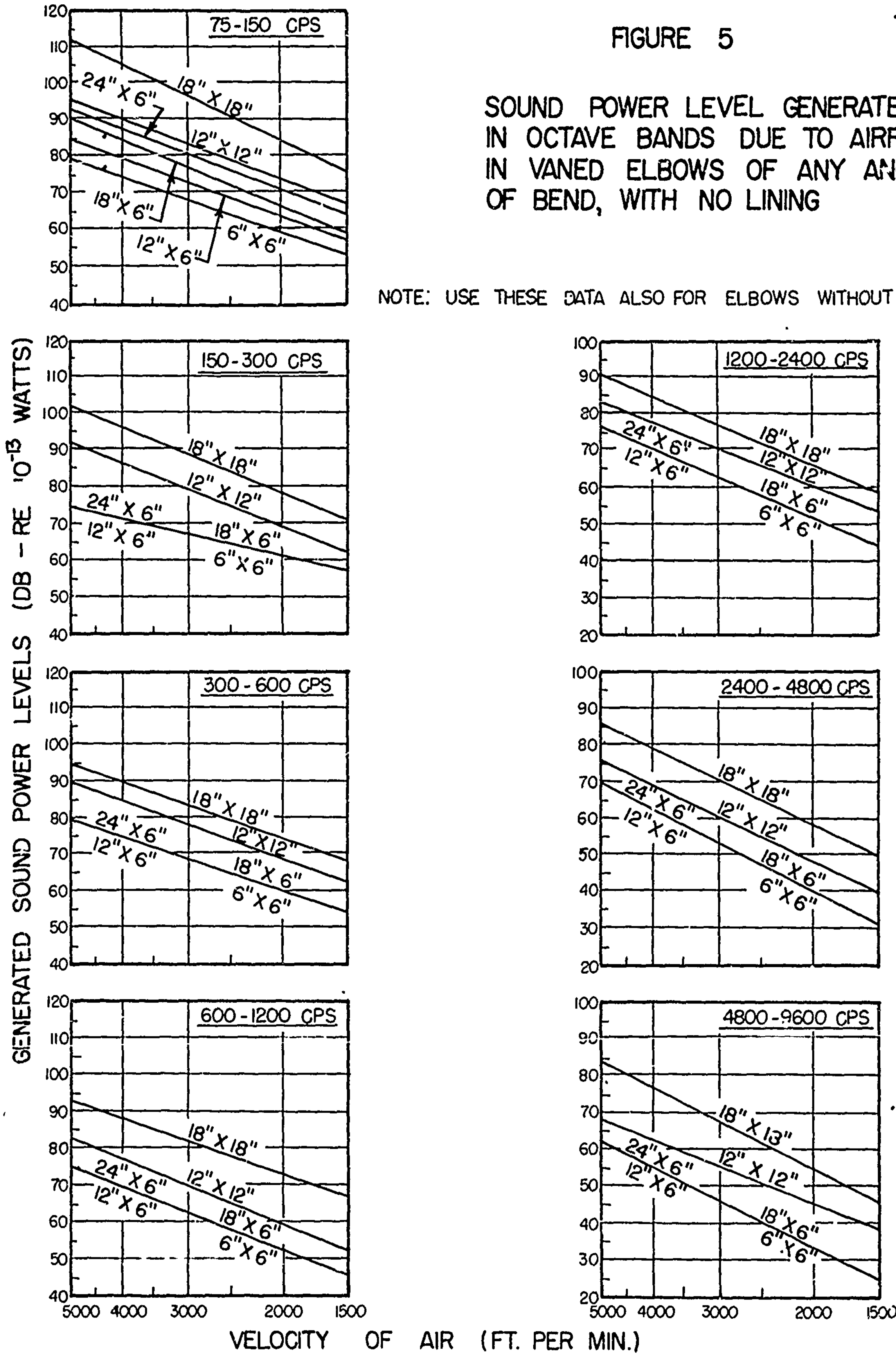


FIGURE 6

SOUND POWER LEVEL ATTENUATION OR GENERATION CHACTERISTICS OF NAVY STANDARD DIFFUSER, EXHAUST AND CONE TYPE TERMINALS (WITHOUT AIRFLOW)

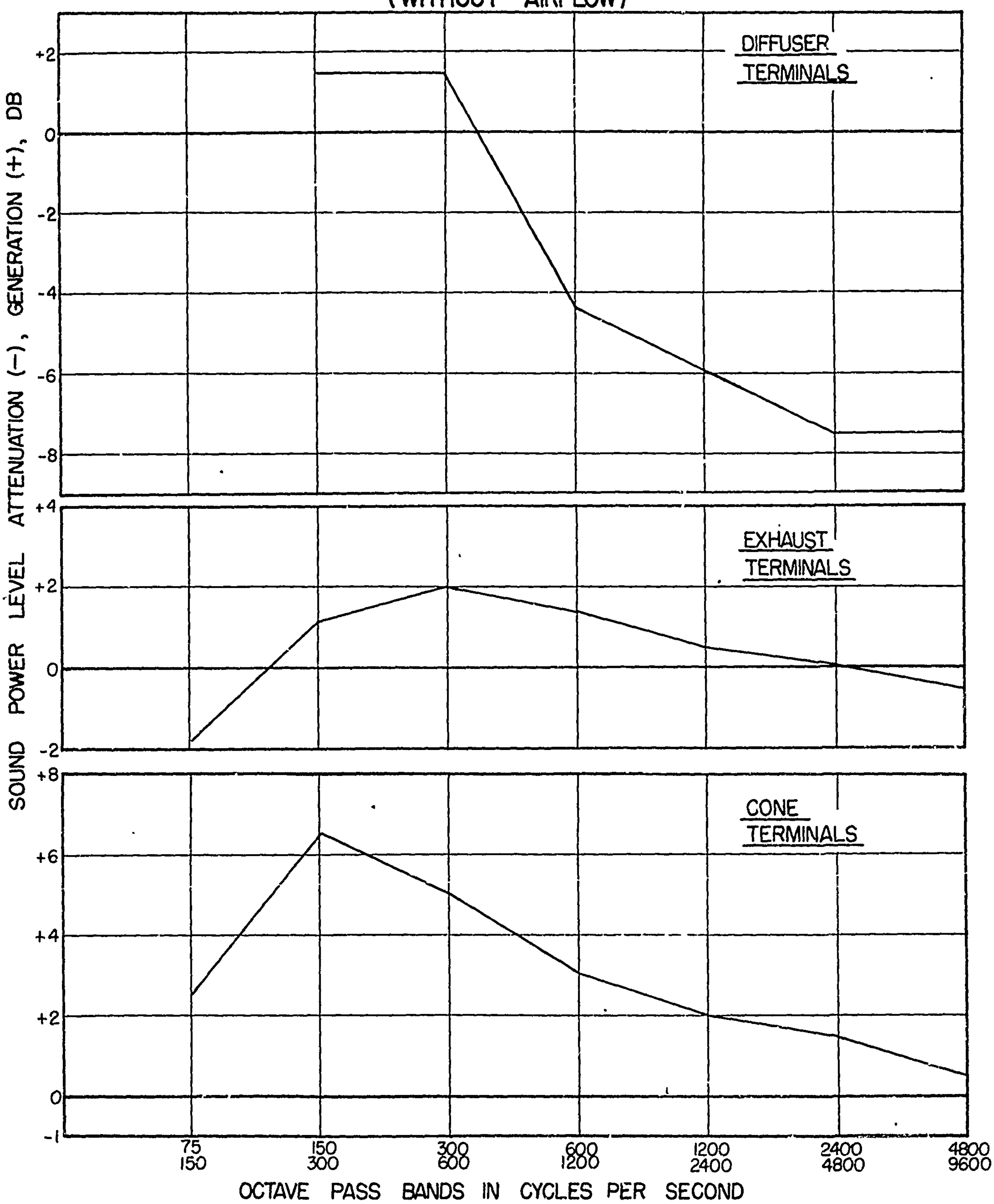


FIGURE 7
AVERAGE SOUND POWER LEVELS OF NAVY STANDARD CONE TERMINALS
(DUE TO AIRFLOW)

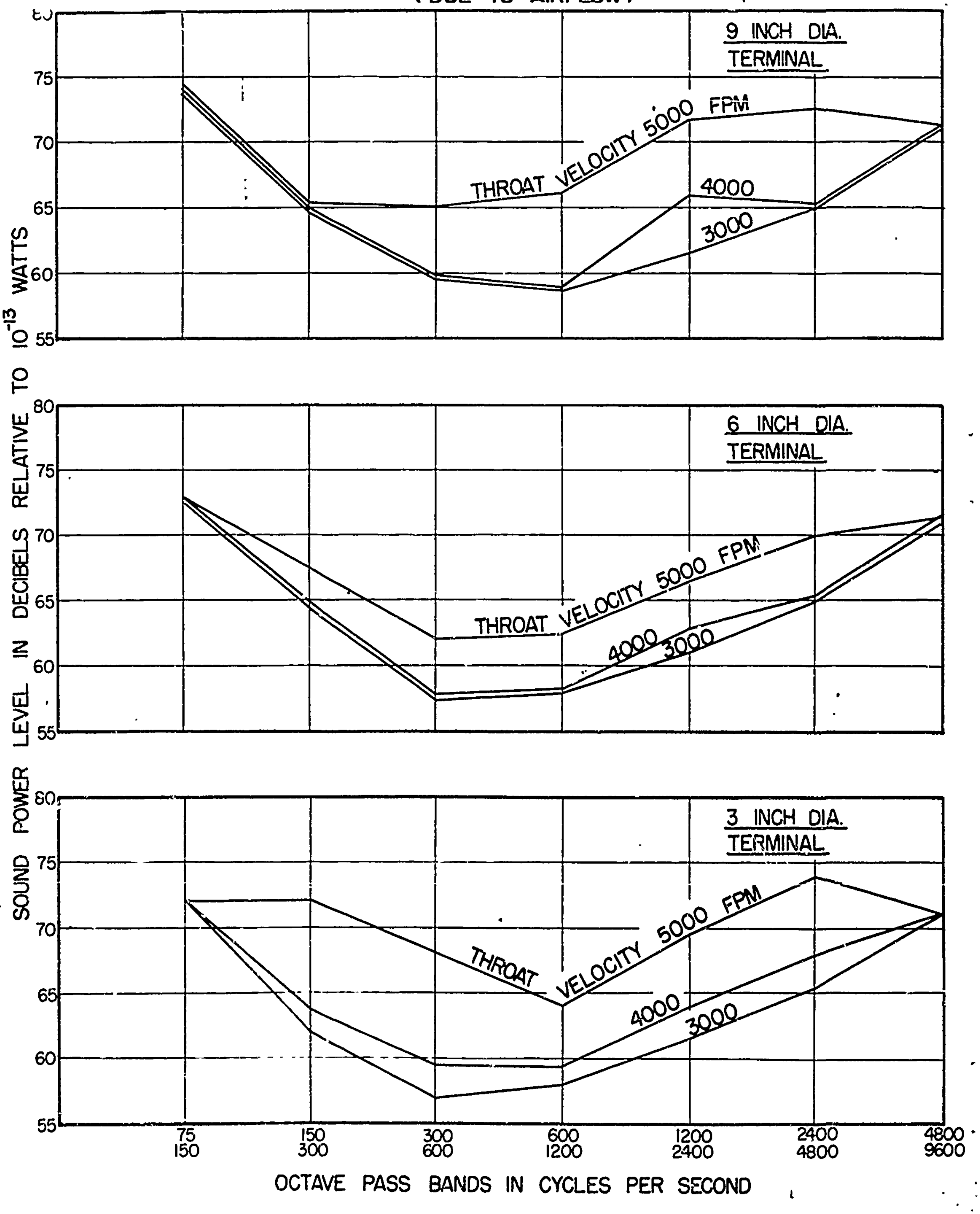


FIGURE 8
AVERAGE SOUND POWER LEVELS OF NAVY
STANDARD EXHAUST TERMINALS
(DUE TO AIRFLOW)

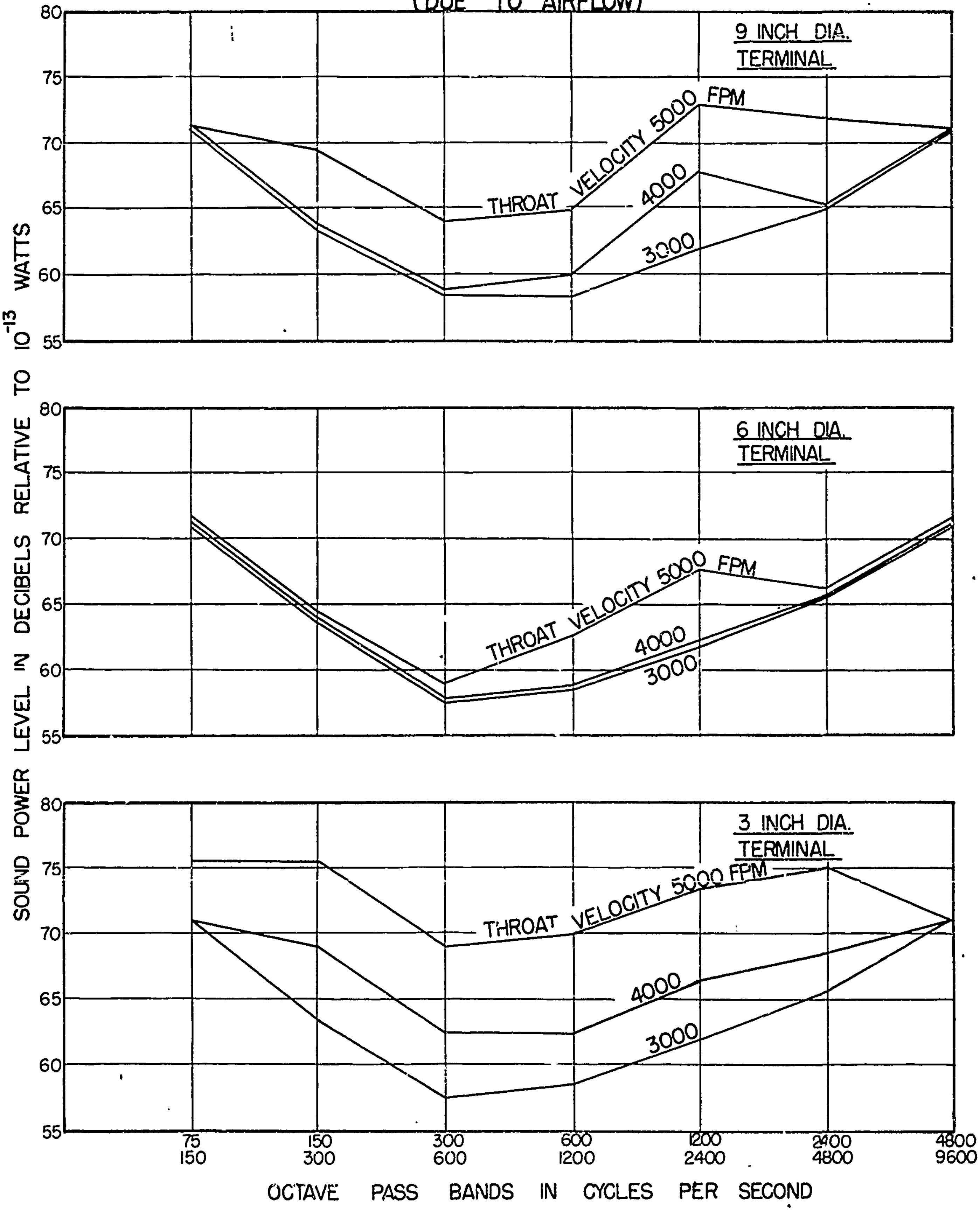


FIGURE 9
AVERAGE SOUND POWER LEVELS OF NAVY STANDARD DIFFUSER TERMINALS (DUE TO AIRFLOW)

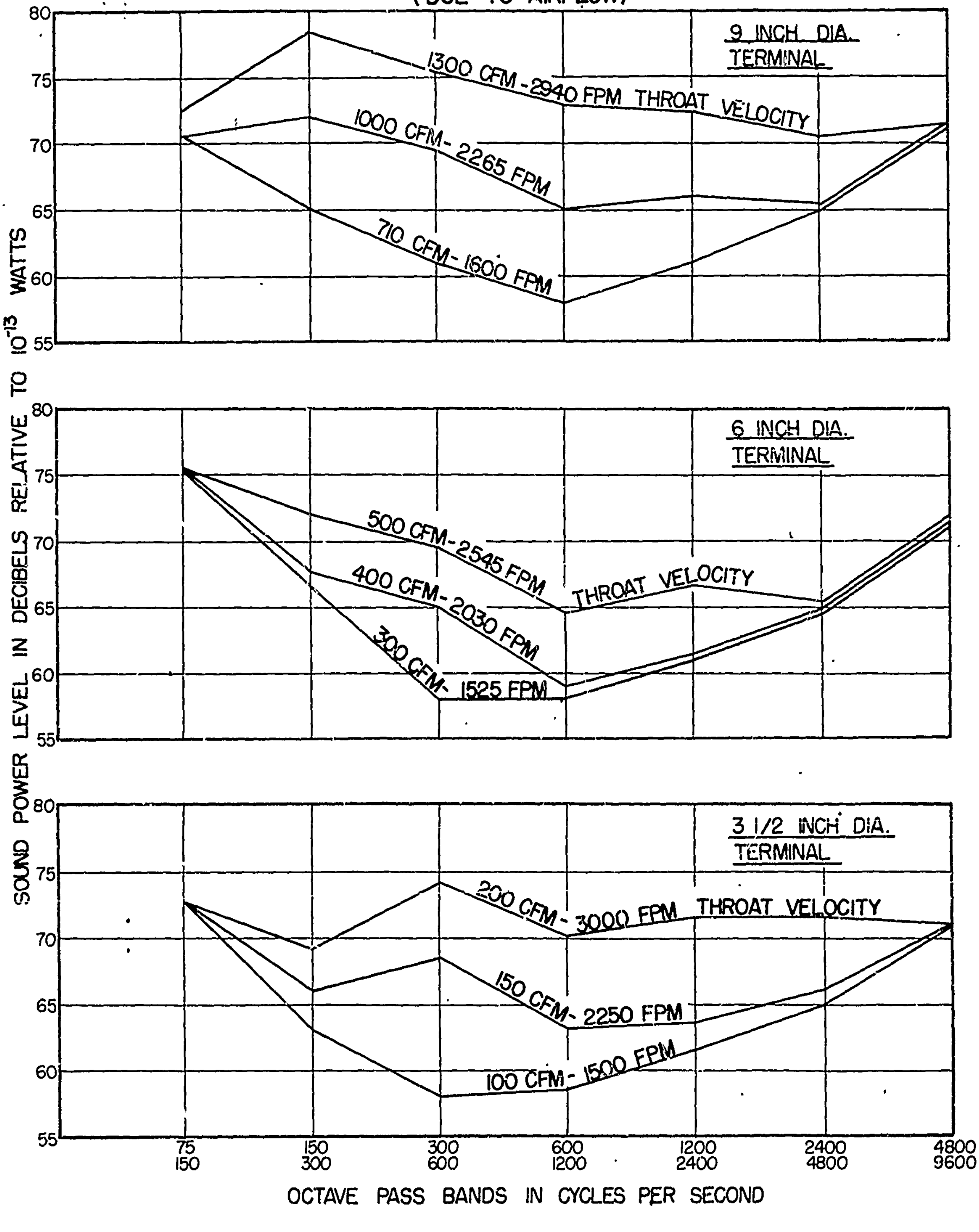
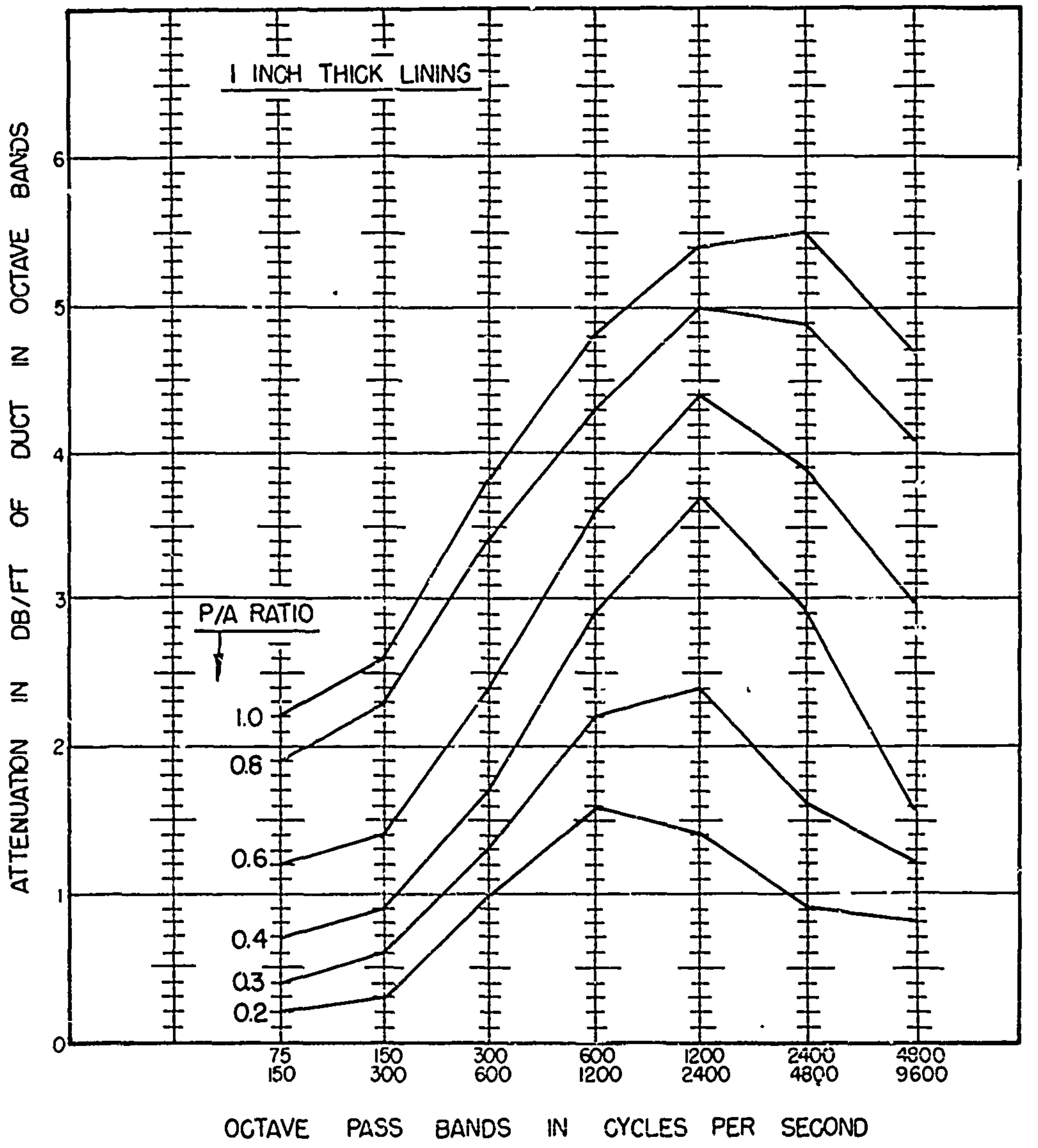


FIGURE 10

SOUND POWER LEVEL ATTENUATION IN OCTAVE BANDS IN STRAIGHT DUCTS LINED ON FOUR SIDES WITH 1" THICK NAVY STANDARD FIBERGLASS AND PERFORATED ALUMINUM, NO AIR FLOW

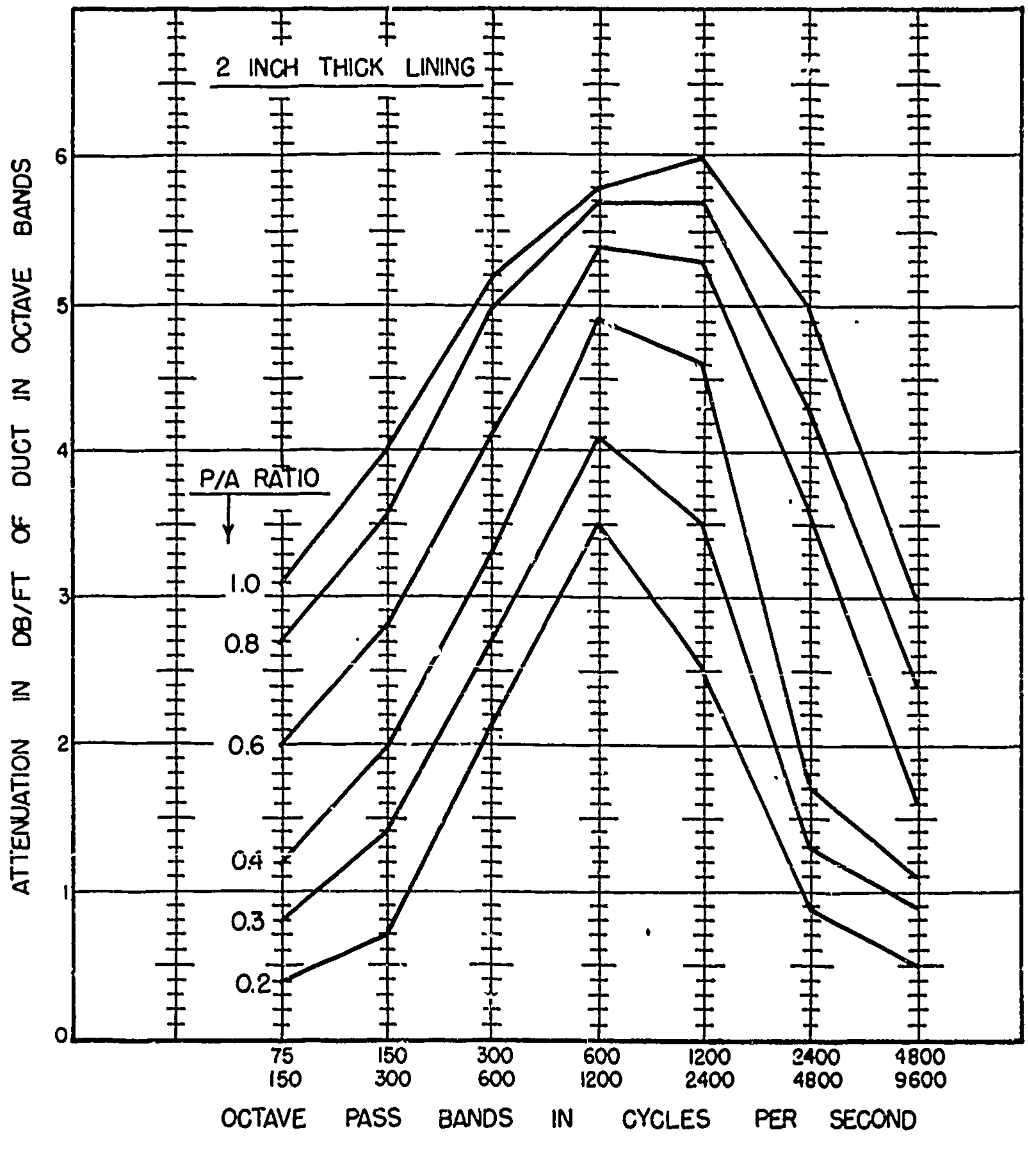


NOTES:

1. $\frac{P}{A} = \frac{\text{PERIMETER (INCHES)}}{\text{CROSS SECT. AREA (SQ.IN.)}}$; PERIMETER AND AREA ARE INSIDE DUCT LINING.
2. CURVES SHOWN MAY NOT BE USED FOR SINGLE FREQUENCY SOURCES.
3. FOR EITHER ROUND OR RECTANGULAR DUCTS WHOSE P/A RATIO IS NOT LISTED, ESTIMATES OF ATTENUATION MAY BE MADE BY INTERPOLATING BETWEEN CURVES.
4. 25 DB IS THE PRACTICAL MAXIMUM ATTENUATION WHICH CAN BE ATTAINED IN DUCTS IN WHICH AIR FLOWS. THIS DETERMINES OPTIMUM LENGTHS OF DUCT LININGS FOR THE VARIOUS OCTAVE BANDS.

FIGURE II

SOUND POWER LEVEL ATTENUATION IN OCTAVE BANDS IN STRAIGHT DUCTS LINED ON FOUR SIDES WITH 2" THICK NAVY STANDARD FIBERGLASS AND PERFORATED ALUMINUM, NO AIRFLOW



NOTES:

1. $\frac{P}{A} = \frac{\text{PERIMETER (INCHES)}}{\text{CROSS SECT. AREA (SQ. IN.)}}$ PERIMETER AND AREA ARE INSIDE DUCT LINING.
2. CURVES SHOWN MAY NOT BE USED FOR SINGLE FREQUENCY SOURCES.
3. FOR EITHER ROUND OR RECTANGULAR DUCTS WHOSE P/A RATIO IS NOT LISTED, ESTIMATES OF ATTENUATION MAY BE MADE BY INTERPOLATING BETWEEN CURVES.
4. 25 DB IS THE PRACTICAL MAXIMUM ATTENUATION WHICH CAN BE ATTAINED IN DUCTS IN WHICH AIR FLOWS. THIS DETERMINES OPTIMUM LENGTHS OF DUCT LININGS FOR THE VARIOUS OCTAVE BANDS.

FIGURE 12

SOUND POWER LEVEL GENERATED IN OCTAVE BANDS DUE TO AIRFLOW IN STRAIGHT DUCTS LINED WITH 1" OR 2" THICK NAVY STANDARD FIBERGLASS AND PERFORATED ALUMINUM, FOR ANY LENGTH OF DUCT.

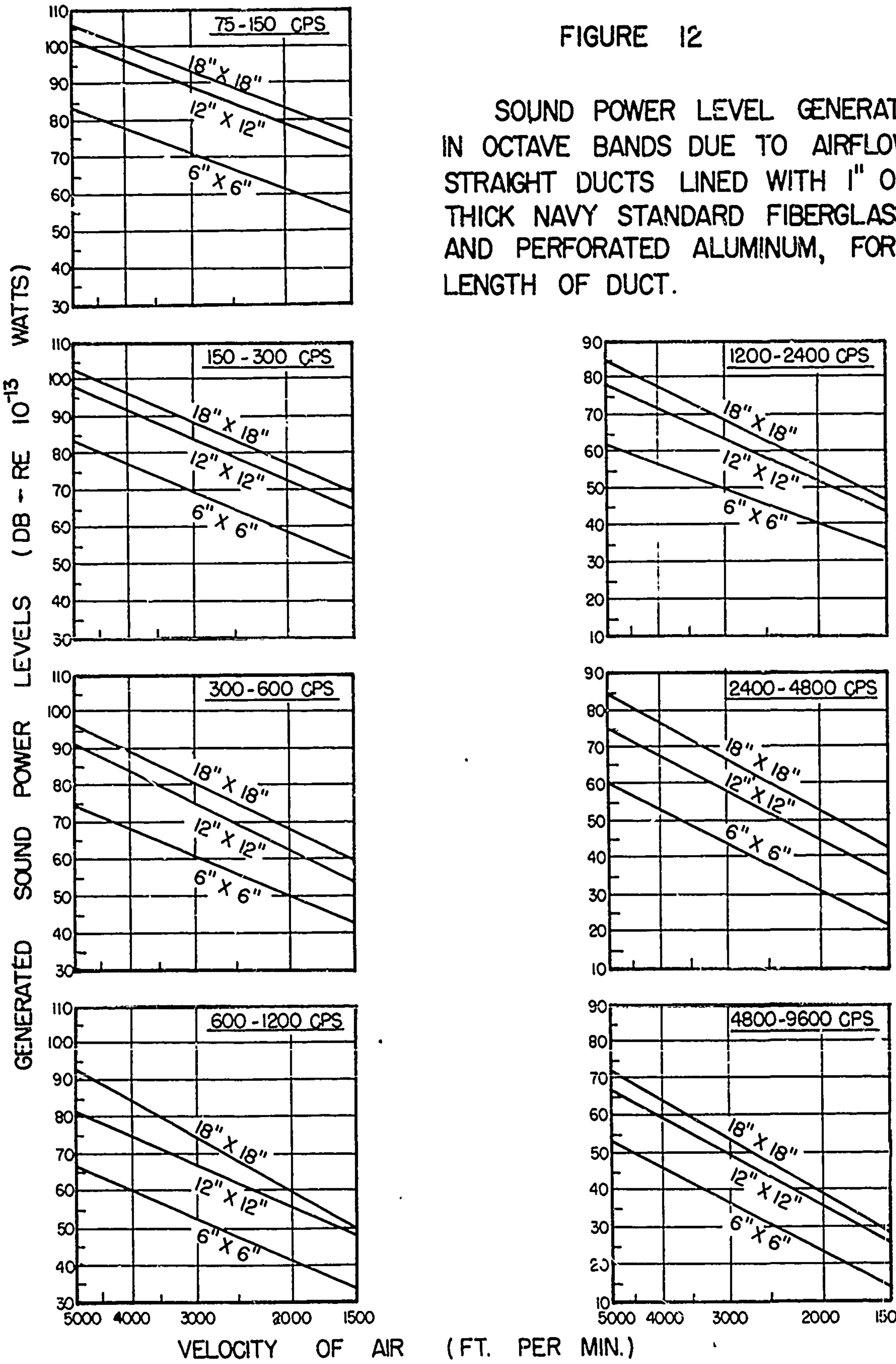


FIGURE 13

DESIGN CURVES FOR PREDICTING SOUND POWER LEVEL ATTENUATION OF RECTANGULAR INTAKE BOXES (WITHOUT INTERNAL BAFFLES AND LINED WITH NAVY STANDARD FIBERGLASS AND PERFORATED ALUMINUM) AS A FUNCTION OF SOUND ABSORPTION COEFFICIENT (α) AND TOTAL INTERNAL SURFACE AREA

AVERAGE SOUND ABSORPTION COEFFICIENT (α) FOR NAVY STANDARD FIBERGLASS (MIL-I-15365B)

	OCTAVE PASS BANDS CPS						
	75 150	150 300	300 600	600 1200	1200 2400	2400 4800	4800 9600
1" THICK BLANKET	0.14	0.22	0.45	0.69	0.77	0.85	0.85
2" THICK BLANKET	0.22	0.42	0.72	0.92	0.87	0.91	0.91

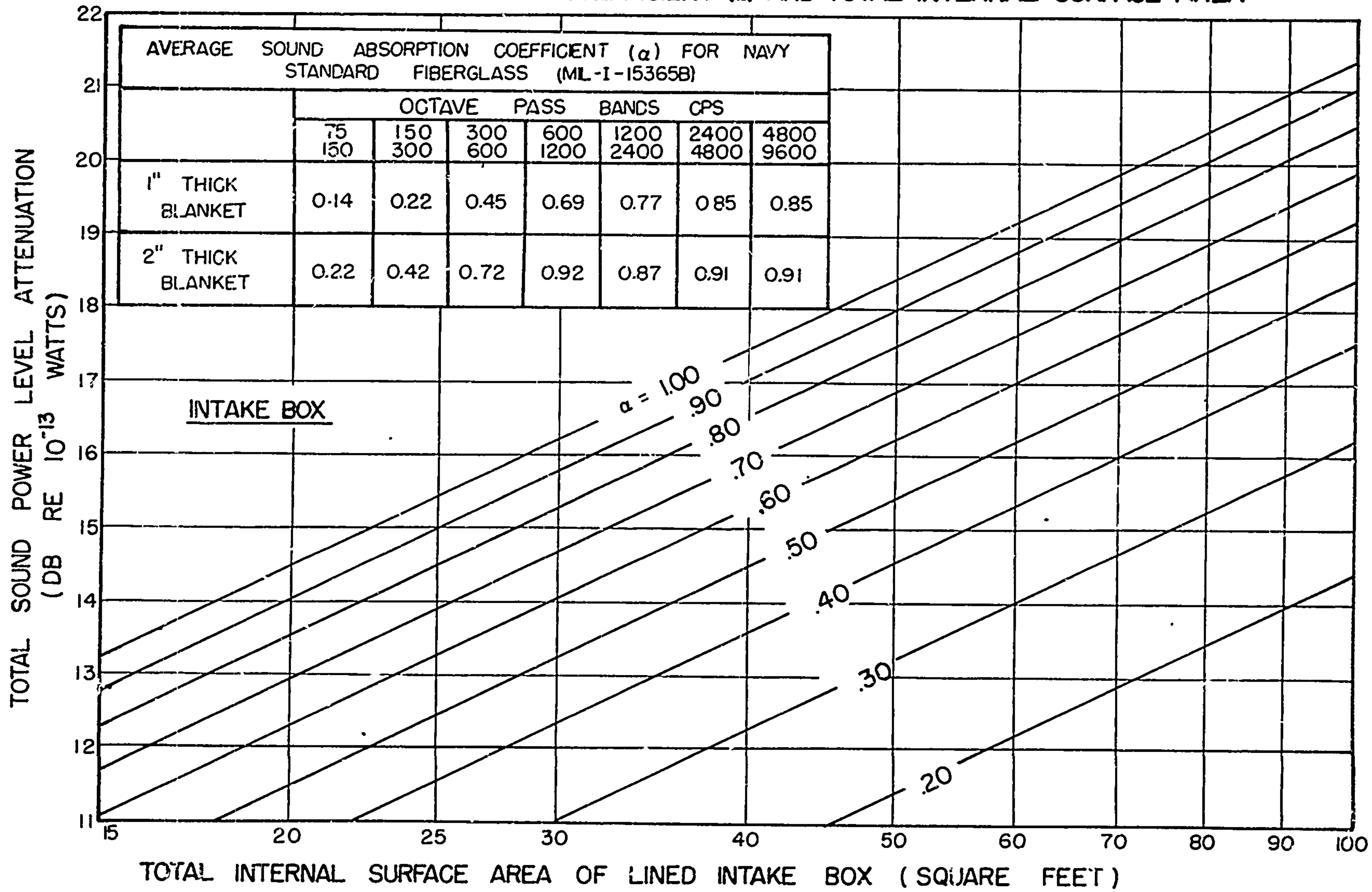
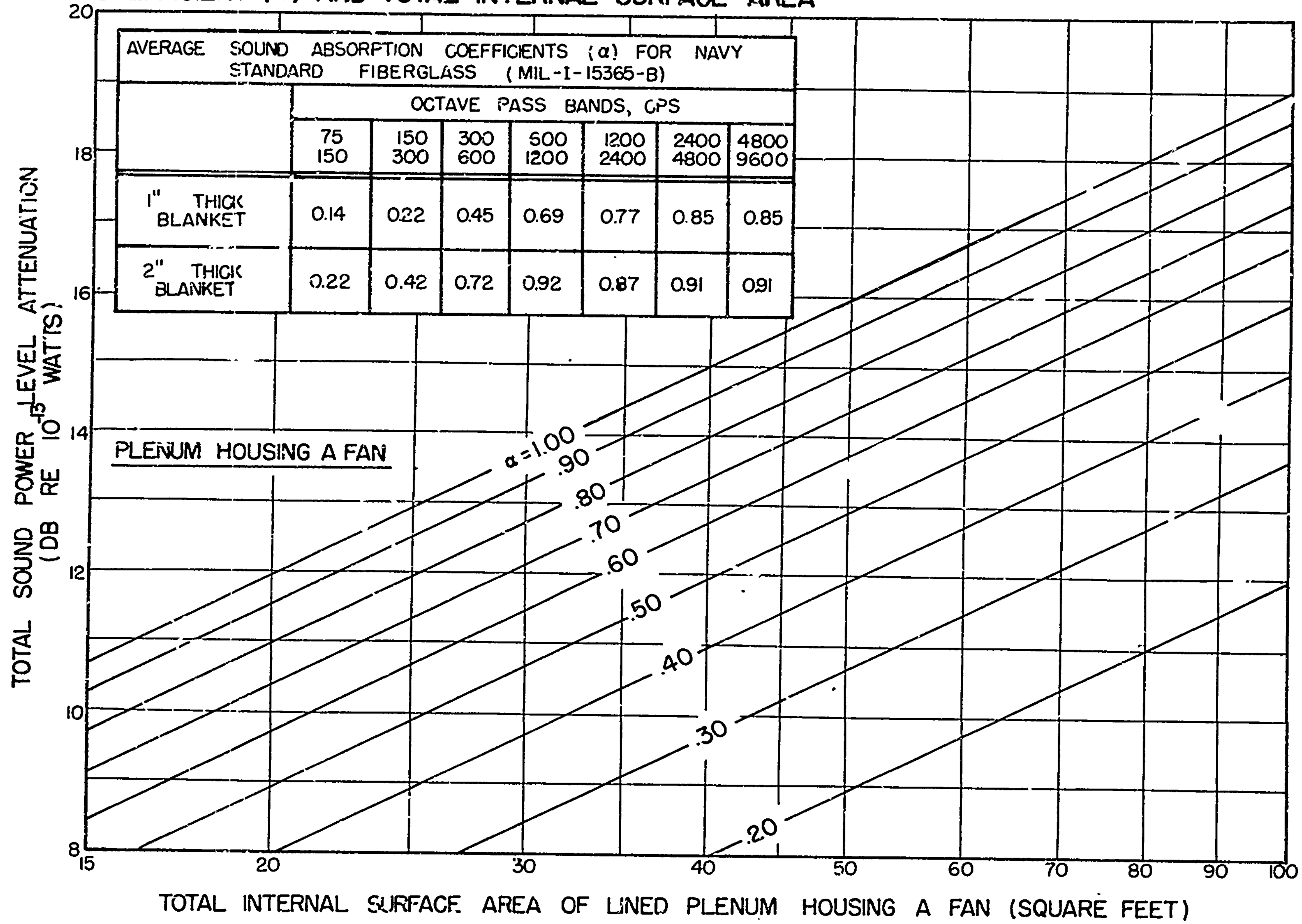


FIGURE 14

DESIGN CURVES FOR PREDICTING SOUND POWER LEVEL ATTENUATION OF RECTANGULAR PLENUMS HOUSING A FAN (WITHOUT INTERNAL BAFFLES AND LINED WITH NAVY STANDARD FIBERGLASS AND PERFORATED ALUMINUM) AS A FUNCTION OF SOUND ABSORPTION COEFFICIENT (α) AND TOTAL INTERNAL SURFACE AREA

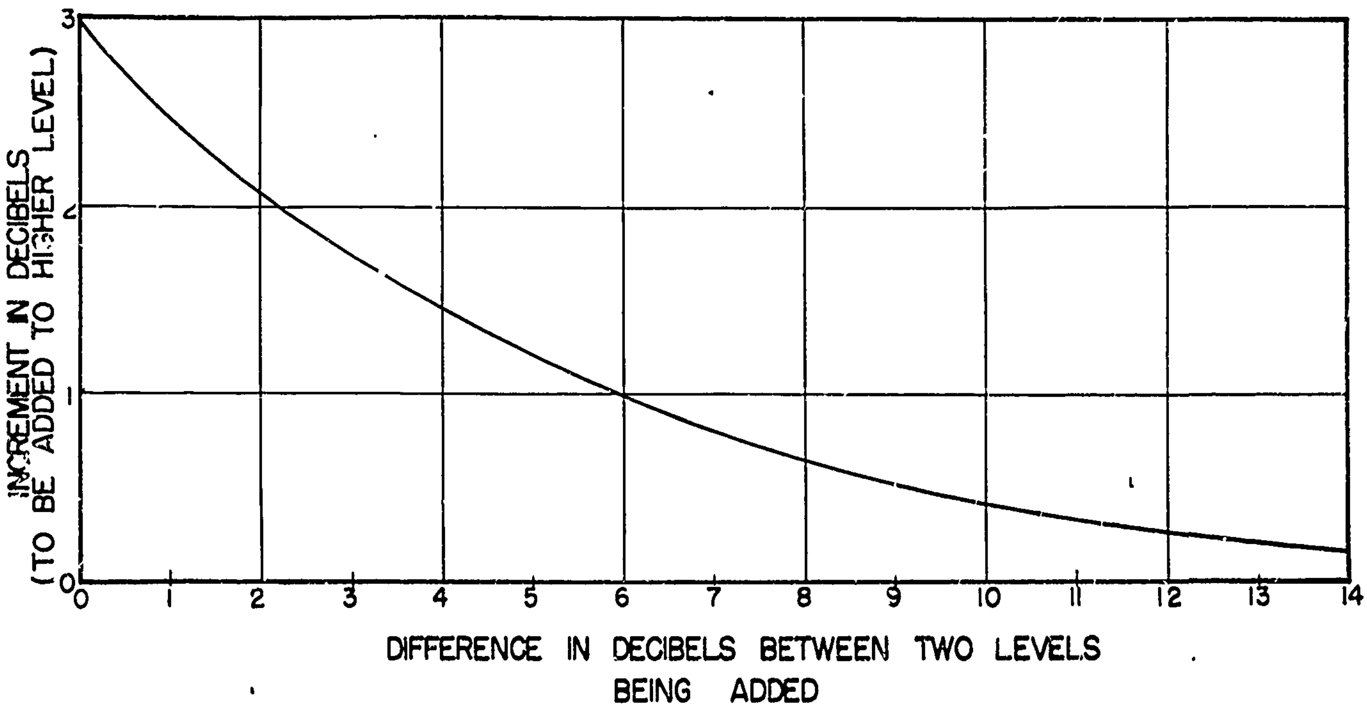


AVERAGE SOUND ABSORPTION COEFFICIENTS (α) FOR NAVY STANDARD FIBERGLASS (MIL-I-15365-B)

	OCTAVE PASS BANDS, CPS						
	75 150	150 300	300 600	600 1200	1200 2400	2400 4800	4800 9600
1" THICK BLANKET	0.14	0.22	0.45	0.69	0.77	0.85	0.85
2" THICK BLANKET	0.22	0.42	0.72	0.92	0.87	0.91	0.91

FIGURE 15

CHART FOR COMBINING NOISE LEVELS



3ND-PAPO-6592

U.S. Naval Applied Science Laboratory.
Project 5662-2. Final Report.
ESTIMATING METHOD FOR PREDICTING NOISE ORIGINATING IN AIR CONDITIONING SYSTEMS ON NAVAL VESSELS. by F. B. Holgate, L. D. Shapiro and A. Simowitz. Final Report. 7 Aug. 1964. 15 p. figs. tables.
UNCLASSIFIED

A method for predicting noise levels, in terms of sound power in octave bands, generated by air conditioning or ventilation systems on submarines and surface vessels, has been developed and reported. This method enables the designer to predict system noise prior to construction, and where necessary, to reduce system noise to specified limits by use of noise reduction devices.

1. Air conditioning equipment - Noise
2. Noise - Reduction
3. Naval vessels - Acoustic properties
I. Holgate, F. B.
II. Shapiro, L. D.
III. Simowitz, A.
IV. SF 013 1109

UNCLASSIFIED

U.S. Naval Applied Science Laboratory.
Project 5662-2. Final Report.
ESTIMATING METHOD FOR PREDICTING NOISE ORIGINATING IN AIR CONDITIONING SYSTEMS ON NAVAL VESSELS. by F. B. Holgate, L. D. Shapiro and A. Simowitz. Final Report. 7 Aug. 1964. 15 p. figs. tables.
UNCLASSIFIED

A method for predicting noise levels, in terms of sound power in octave bands, generated by air conditioning or ventilation systems on submarines and surface vessels, has been developed and reported. This method enables the designer to predict system noise prior to construction, and where necessary, to reduce system noise to specified limits by use of noise reduction devices.

1. Air conditioning equipment - Noise
2. Noise - Reduction
3. Naval vessels - Acoustic properties
I. Holgate, F. B.
II. Shapiro, L. D.
III. Simowitz, A.
IV. SF 013 1109

UNCLASSIFIED

U.S. Naval Applied Science Laboratory.
Project 5662-2. Final Report.
ESTIMATING METHOD FOR PREDICTING NOISE ORIGINATING IN AIR CONDITIONING SYSTEMS ON NAVAL VESSELS. by F. B. Holgate, L. D. Shapiro and A. Simowitz. Final Report. 7 Aug. 1964. 15 p. figs. tables.
UNCLASSIFIED

A method for predicting noise levels, in terms of sound power in octave bands, generated by air conditioning or ventilation systems on submarines and surface vessels, has been developed and reported. This method enables the designer to predict system noise prior to construction, and where necessary, to reduce system noise to specified limits by use of noise reduction devices.

1. Air conditioning equipment - Noise
2. Noise - Reduction
3. Naval vessels - Acoustic properties
I. Holgate, F. B.
II. Shapiro, L. D.
III. Simowitz, A.
IV. SF 013 1109

UNCLASSIFIED

U.S. Naval Applied Science Laboratory.
Project 5662-2. Final Report.
ESTIMATING METHOD FOR PREDICTING NOISE ORIGINATING IN AIR CONDITIONING SYSTEMS ON NAVAL VESSELS. by F. B. Holgate, L. D. Shapiro and A. Simowitz. Final Report. 7 Aug. 1964. 15 p. figs. tables.
UNCLASSIFIED

A method for predicting noise levels, in terms of sound power in octave bands, generated by air conditioning or ventilation systems on submarines and surface vessels, has been developed and reported. This method enables the designer to predict system noise prior to construction, and where necessary, to reduce system noise to specified limits by use of noise reduction devices.

1. Air conditioning equipment - Noise
2. Noise - Reduction
3. Naval vessels - Acoustic properties
I. Holgate, F. B.
II. Shapiro, L. D.
III. Simowitz, A.
IV. SF 013 1109

UNCLASSIFIED

REPORT ABSTRACT FORM
3ND-NYNS-907-910

Leave at least one space free in front of these four lines.

U.S. Naval Applied Science Laboratory.
Project 5662-2. Final Report.
ESTIMATING METHOD FOR PREDICTING NOISE ORIGINATING IN AIR CONDITIONING SYSTEMS ON NAVAL VESSELS. by F. B. Holgate, L. D. Shapiro and A. Simowitz. Final Report. 7 Aug. 1964. 15 p. figs. tables.
UNCLASSIFIED

A method for predicting noise levels, in terms of sound power in octave bands, generated by air conditioning or ventilation systems on submarines and surface vessels, has been developed and reported. This method enables the designer to predict system noise prior to construction, and where necessary, to reduce system noise to specified limits by use of noise reduction devices.

1. Air conditioning equipment - Noise
2. Noise - Reduction
3. Naval vessels - Acoustic properties

I. Holgate, F. B.
II. Shapiro, L. D.
III. Simowitz, A.
IV. SF 013 1109

UNCLASSIFIED

U.S. Naval Applied Science Laboratory.
Project 5662-2. Final Report.
ESTIMATING METHOD FOR PREDICTING NOISE ORIGINATING IN AIR CONDITIONING SYSTEMS ON NAVAL VESSELS. by F. B. Holgate, L. D. Shapiro and A. Simowitz. Final Report. 7 Aug. 1964. 15 p. figs. tables.
UNCLASSIFIED

A method for predicting noise levels, in terms of sound power in octave bands, generated by air conditioning or ventilation systems on submarines and surface vessels, has been developed and reported. This method enables the designer to predict system noise prior to construction, and where necessary, to reduce system noise to specified limits by use of noise reduction devices.

1. Air conditioning equipment - Noise
2. Noise - Reduction
3. Naval vessels - Acoustic properties

I. Holgate, F. B.
II. Shapiro, L. D.
III. Simowitz, A.
IV. SF 013 1109

UNCLASSIFIED

U.S. Naval Applied Science Laboratory.
Project 5662-2. Final Report.
ESTIMATING METHOD FOR PREDICTING NOISE ORIGINATING IN AIR CONDITIONING SYSTEMS ON NAVAL VESSELS. by F. B. Holgate, L. D. Shapiro and A. Simowitz. Final Report. 7 Aug. 1964. 15 p. figs. tables.
UNCLASSIFIED

A method for predicting noise levels, in terms of sound power in octave bands, generated by air conditioning or ventilation systems on submarines and surface vessels, has been developed and reported. This method enables the designer to predict system noise prior to construction, and where necessary, to reduce system noise to specified limits by use of noise reduction devices.

1. Air conditioning equipment - Noise
2. Noise - Reduction
3. Naval vessels - Acoustic properties

I. Holgate, F. B.
II. Shapiro, L. D.
III. Simowitz, A.
IV. SF 013 1109

UNCLASSIFIED

U.S. Naval Applied Science Laboratory.
Project 5662-2. Final Report.
ESTIMATING METHOD FOR PREDICTING NOISE ORIGINATING IN AIR CONDITIONING SYSTEMS ON NAVAL VESSELS. by F. B. Holgate, L. D. Shapiro and A. Simowitz. Final Report. 7 Aug. 1964. 15 p. figs. tables.
UNCLASSIFIED

A method for predicting noise levels, in terms of sound power in octave bands, generated by air conditioning or ventilation systems on submarines and surface vessels, has been developed and reported. This method enables the designer to predict system noise prior to construction, and where necessary, to reduce system noise to specified limits by use of noise reduction devices.

1. Air conditioning equipment - Noise
2. Noise - Reduction
3. Naval vessels - Acoustic properties

I. Holgate, F. B.
II. Shapiro, L. D.
III. Simowitz, A.
IV. SF 013 1109

UNCLASSIFIED

REPORT ABSTRACT FORM
3ND-NYNS-907-910

Leave at least one space free in front of these four lines.