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**AERODYNAMIC NOISE AND THE ESTIMATION
OF NOISE IN AIRCRAFT**

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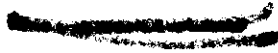


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FOREWORD

The work reported here was accomplished by Dynamics Branch, Aircraft Laboratory, Wright-Patterson Air Force Base, Ohio, under Research and Development Order No. 455-49C, "Aerodynamic and Jet Noise in the Subsonic Speed Range," with O. R. Rogers and R. F. Cook acting as project engineers.

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ABSTRACT

Aircraft noise in the frequency range above 600 cps which produces the greatest interference with speech communication, can be controlled by practical amounts of sound insulation and can be estimated from the indicated airspeed in most jet propelled or multi-engine propeller driven aircraft. Since interference with speech communication is the most serious effect of aircraft noise, the methods contained in this report for estimation of the insulation required enable the aircraft designers to provide for necessary sound insulation in the earliest design stages.

The principal source responsible for noise above 600 cps in the aforementioned aircraft types is the airflow over the fuselage and this noise is found to depend approximately upon the 2.75 power of the indicated air speed. Sound reduction afforded by the insulation is also found to be simply related to the surface density of the batting plus that of any non-porous septa included in the blanket.

The security classification of the title of this report is UNCLASSIFIED.

PUBLICATION REVIEW

This report has been reviewed and is approved.

FOR THE COMMANDING GENERAL:

J. O. Lippman
for
R. G. RUEGG
Colonel, USAF
Chief, Aircraft Laboratory
Directorate of Laboratories

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A. INTRODUCTION

Prior investigations of aircraft noise have established fairly definitely the characteristics of noise produced by the propellers, the reciprocating engine, and the jet engine. Although these results are somewhat scattered throughout the literature it is possible to form a fair estimate of the noise inside an aircraft cabin as produced by these sources. It is also possible to estimate the change in noise resulting from a change in the operation or design parameters of such sources. In addition to these sources, which are associated with the propulsion of the aircraft, there are various miscellaneous sources such as ventilation equipment, pressurization equipment, electrical equipment, etc. These are of importance chiefly when they are located within the cabin concerned.

After all the foregoing noise types have been removed there remains the noise which arises from the motion of the aircraft through the air. In the present report such noise will be called Aerodynamic Noise and includes the various wind whistles at openings or cracks as well as an additional component which is associated with the flow of air over the fuselage skin. The noise in a glider or in an airplane in a glide or dive is therefore typically aerodynamic. As will be demonstrated in the body of this report Aerodynamic Noise is the predominant type at frequencies above 600 cps in certain classes of aircraft comprising a very large portion of Air Force airplanes.

Coincidentally this frequency range in which Aerodynamic Noise is often predominant is also the range in which noise interferes most noticeably with speech communication. As a matter of fact Beranek (Ref. 1) has demonstrated that an average of measured noise levels in the three octave frequency bands starting at 600 cps is a satisfactory measure of the speech interference effects of aircraft noise. Also this same frequency range is the one in which sound insulation, as limited by the space and weight requirements of aircraft, effects significant reductions in the noise. At frequencies below 600 cps practical aircraft sound insulation can furnish some noise reduction but with present techniques this reduction is no more than 2 or 3 decibels. Since the need for adequate communication furnishes the paramount reason for sound insulation of aircraft, a study of aerodynamic noise and methods for its reduction including insulation forms a coherent and the major division of the subject of aircraft noise control.

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It is the purpose of this report to present a method for estimating aerodynamic noise as it appears inside aircraft from a knowledge of the insulation design, the aircraft design, and the operating characteristics of the aircraft. From this information it will also be possible to determine what changes are necessary to reach specified aircraft sound levels in those frequency bands in which aerodynamic noise is predominant.

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B. METHOD FOR ESTIMATING SOUND REDUCTION

When a source of sound is located outside of an inclosure the walls of the inclosure furnish a reduction of noise from the outside to the inside. Sound insulation has the simple purpose of increasing this sound reduction and knowledge of the reduction afforded in a given case is necessary to determine outside noise levels from measurements of the noise levels inside or vice versa.

A simple method of estimating the sound reduction is based on the assumption of a nearly uniform acoustical inclosure immersed in a nearly uniform sound field which produces a nearly uniform field inside the inclosure. Under these assumptions the noise reduction is (See Ref. 2)

$$N. R. = 10 \log \left(1 + \frac{\alpha}{\tau} \right) \tag{1}$$

where α and τ are respectively the average absorption and transmission coefficients of the bounding surfaces. If the inclosure is not uniform the coefficients α and τ are determined by:

$$\alpha = (S_1 \alpha_1 + S_2 \alpha_2 + S_3 \alpha_3 + \dots) / S \tag{2}$$

$$\tau = (S_1 \tau_1 + S_2 \tau_2 + S_3 \tau_3 + \dots) / S \tag{3}$$

$$S_1 + S_2 + S_3 + \dots = S \quad \text{the total boundary area and } \alpha_1, \alpha_2,$$

α_3, \dots and $\tau_1, \tau_2, \tau_3, \dots$ are the particular α 's and τ 's for the particular portion of the boundary area so designated. Now let

$$\sum S_i \alpha_i = A \quad \text{and} \quad \sum S_i \tau_i = T \quad \text{and equation (1) becomes}$$

$$N. R. = 10 \log \left(1 + \frac{A}{T} \right) \tag{4}$$

where A is the total number of absorption units and T is the total number of transmission units of the inclosure. Equation (4) is accurate only if the noise is distributed uniformly throughout the inclosure, which, in general, will not be the case for an actual airplane due to standing waves, small air leaks, etc., within the compartment. However, valid approximations of the noise-level reductions can be made by use

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of equation (4) if the wave length is considerably smaller than the inclosure dimension. It will be assumed in this report that this condition is met at frequencies above 600 cps for the airplanes involved.

The foregoing noise reduction applies to single frequency tones, however aircraft noise measurements are usually made to give the combined levels in an octave wide band of tones.

Both A and T for a given inclosure are functions of the sound frequency and therefore the proper selection of the frequency for computing these values must be made. Figure 1 illustrates the general trends of the absorption and transmission coefficients, neither of which are ever greater than one, for absorptive type structures for frequencies above 600 cps. It is readily seen from the above figure for a blanket utilizing a porous trim cloth, that if conservative results are to be obtained the lowest frequency of the frequency octave in question should be used to calculate the values of A and T. For blankets utilizing a non-porous trim cloth the frequency which gives the most conservative results should be used. This frequency will, in most cases, be the lowest frequency of the octave in question.

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C. EMPIRICAL RESULTS ON AERODYNAMIC NOISE

Aerodynamic noise has been measured in flight in an XCG-4 glider and an F-80 airplane (Refs. 3 and 4).

Measurements in the glider were made both in a free glide and when the glider was being towed behind another airplane. Attempts were made by means of narrow band analyzers to measure the propeller or exhaust components from the tow plane without success. It was also found impossible to hear these above the glider noise. When the measurements in octave bands above 600 cps are plotted against the logarithm of indicated airspeed a nearly straight line results which shows no evidence of a discontinuity between the points taken in a glide and those taken when the glider was towed. It therefore seems certain that these measurements are not affected by the tow plane and that all points representing the glider are aerodynamic noise.

Measurements in the F-80 were made both in a glide or dive with the engine idle and in level flight or a climb with engine at normal rated speed. This pair of measurements was repeated at several air speeds. This particular airplane was equipped with special engine mounts for the purpose of minimizing structural vibration and noise therefrom. When the airplane was operated at normal rated engine speeds, the measured levels increased slightly over the idle condition but never by more than two or three decibels (see Fig. 2). By known methods for calculating the resulting level from two sources, each producing the same noise, it can be concluded that the engine noise never exceeded the aerodynamic noise even at normal rated engine speed and therefore measurements made with the engine idle represent aerodynamic noise alone.

Of the parameters on which aerodynamic noise might depend, airspeed is the most obvious. In addition temperature and pressure might conceivably affect the aerodynamic noise. Both are changed by actually flying the airplane at different altitudes and this was done in the case of the F-80. Figure 3 shows measurements at two altitudes against indicated air speed. There is a definite change with increasing altitude but it is small and is not in the same direction in all frequency bands. Therefore the effects of altitude, temperature, and airspeed may be included by considering aerodynamic noise as a function of indicated airspeed to a first approximation.

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In addition to the airspeed it would appear that the shape of the airplane could have some effect and the sound reduction afforded by the fuselage walls and insulation could certainly affect the aerodynamic noise levels obtained inside the aircraft. To eliminate the latter effect the sound reduction from outside to inside has been calculated by methods of the preceding section under the assumption that the airplane is immersed in a uniform random external noise field and this normal reduction has been added to the inside noise measurements. The result then gives the external random field which would produce the measured internal noise levels. The external field so computed will be called the external aerodynamic noise without, however, implying that a true noise field of that level and frequency actually exists outside the airplane. In the opinion of the authors aerodynamic noise is produced mostly by the pressure fluctuation in a turbulent boundary layer and therefore conditions outside the airplane are more adequately described by vorticity in the boundary layer than by a sound field which is derived classically under the assumption that vorticity is absent. In either case external pressure fluctuations will force the fuselage skin to vibrate producing a true sound field inside the aircraft.

If the external aerodynamic noise levels of the glider and F-80 are plotted against indicated airspeed, Figures 4, 5, and 6 are obtained for the three frequency bands 600-1200 cps, 1200-2400 cps, and 2400-9600 cps. Examination of these figures leaves some doubt as to whether or not there is a real difference between the two aircraft which if it exists could then be assigned to the difference in shapes. There appears to be a slight difference in slope between the best straight line through the F-80 points and that through the glider points. Further the F-80 points appear to fall below the extension of the glider straight line. However these differences might equally well be due to errors in the calculated sound reduction which were added to the measured values or might simply indicate that the relation of aerodynamic noise level to the logarithm of the indicated airspeed departs slightly from linearity over an extended range of airspeeds. Regardless of the exact relationship, the data in these figures can be approximated for both airplanes within about 3 or 4 db by a straight line drawn through the points. This is well within the accuracy which could be expected of any method of estimating airplane noise.

To the approximation noted it is indicated that the external aerodynamic noise level is not affected by aircraft shapes or sizes since the two aircraft here considered are about as radically different in shape and smoothness of contours as could be expected. It is further indicated that a linear relation of external aerodynamic noise in the frequency range above 600 cps to the logarithm of the indicated airspeed

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will hold approximately in all aircraft under all flight conditions. These tentative conclusions will be further supported by measurements made on other airplanes and discussed in the next section of this report.

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D. ESTIMATION OF EXTERNAL NOISE FOR CERTAIN AIRCRAFT

The validity of the assumption that aerodynamic noise is predominant in many types of aircraft at frequencies above 600 cps can be checked either by comparison of the levels obtained from the preceding section with known levels from other sources or by comparing measured levels in several aircraft with estimated levels of aerodynamic noise obtained from the preceding section. The latter procedure will be followed in this section and agreement between estimated and measured levels will also support the validity of the tentative conclusion reached at the end of the last section.

In order to make this comparison the sound reduction has been calculated for the insulation and fuselage walls of several aircraft on which measurements are available. These sound reductions have been added to the measured levels to give the levels of the external noise field which have then been plotted against indicated air speed in the same manner as the external noise of the preceding section. The results are shown in Figures 7, 8, and 9 while the key to the airplanes used is contained in Table I.

In regard to the calculations of the outside noise-levels of these airplanes, some of which were taken from Reference 5 and some from Air Force experimental data, certain assumptions had to be made. For the airplanes contained in Reference 5 the $\frac{A}{T}$ values had been calculated at frequencies of 1000 and 3000 cps. In order to convert these values to frequencies of 600, 1200 and 2400 cps it was assumed that the total absorption units remained the same. This appears to be a reasonable assumption in that the absorption coefficient does not change appreciably over a small frequency range for frequencies above 600 cps. From experimental data in Reference 6, on noise transmission through various aircraft soundproofing structures, the change in the transmission coefficient from one frequency to another, eg. 600 cps to 1000 cps, can be determined. Therefore, if A remains constant the value of T may be multiplied by the ratio of these transmission coefficients to determine the $\frac{A}{T}$ value at another frequency. The accuracy of this procedure depends on whether the relationship of the transmission coefficient with frequency for these structures is such that the variation from one frequency to another is linear. Over a small frequency range this can be assumed to be true.

It will be noted that most of the points on these graphs are included between two straight lines which are 4 db either side of their median and that these lines have about the same slope as the

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lines used to approximate external aerodynamic noise in the preceding section. Further the points representing the glider and F-80 fall between the two lines so the absolute levels between these lines are consistent with the assumption that points between the lines represent aerodynamic noise. It has also been noted in the preceding section that a ± 4 db accuracy is about all that can be expected in estimating external aerodynamic noise by the simple assumption of a linear relation between the logarithm of the indicated airspeed and the noise level. Thus for noise measurements in most of the airplanes of Figures 7, 8, and 9, agreement is obtained within expected limits between measured noise levels and estimated external aerodynamic noise levels.

In considering those aircraft for which measured points fall outside the band of estimated external aerodynamic noise, there are several reasons why some points will be above the band but only error in the measurement or under-estimation of sound reduction would account for points below the bands. This latter reason is considered quite improbable and very few points should appear below the band. This is confirmed by inspection of the figures. Points would lie above the band if the normal reduction were over-estimated as would occur when air leaks are present or if another source produced noise at a higher level than that of the aerodynamic noise. One or the other of these conditions occurs frequently and data on certain types of aircraft have been eliminated from the graphs to clarify the results. Thus inspection of Table I shows that no aircraft powered by a single reciprocating engine nor an airplane having ejector exhausts has been included. Measurements in such aircraft are without exception higher than the aerodynamic noise levels. Classes of airplanes included in this presentation are turbo-jet and multi-engine propeller driven airplanes as well as a glider. Thus for these latter classes of aircraft it appears possible to estimate noise levels in the frequency range above 600 cps from the relationship between external aerodynamic noise and indicated airspeed by subtracting therefrom the noise reduction afforded by the bounding surfaces of the airplane cabins.

In a certain sense aerodynamic noise forms a minimum below which no changes in engine, propeller, or other noise sources can reduce the observed levels. Thus insulation must be provided to reduce aerodynamic noise to acceptable levels in high speed aircraft but this alone does not insure that the resulting levels will be acceptable unless other noise sources are also controlled by suitable design. Nevertheless engine and propeller noise levels above 600 cps can be reduced below aerodynamic noise levels by proper design using presently available knowledge as is illustrated in many modern aircraft and therefore aerodynamic noise is the prime determinant of the amount of insulation required.

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E. TRANSMISSION AND ABSORPTION OF TYPICAL STRUCTURES

In Section B a method for calculating sound reduction from a knowledge of the transmission and absorption coefficients of the cabin boundary surfaces has been presented. For purposes of calculating this reduction at frequencies above 600 cps these coefficients are required at the lowest frequency of each octave band, i.e., 600 cps, 1200 cps and 2400 cps.

The structures involved are non-porous thin sheets like windows or dural skin and combinations of dural sheets, batting and fabrics. In addition the clothes of personnel and the upholstery of seats furnish absorption which must be added to that furnished by the wall coverings.

Any attempt to obtain the absorption coefficient within an accuracy of less than 10% from a knowledge of material properties leads to considerable complexity. However this accuracy is not necessary because inaccuracies of $\pm 40\%$ in the total absorption produce inaccuracies of about ± 2 db in the sound reduction as calculated by equation (4). Therefore it is not necessary to know the absorption coefficient closer than $\pm 40\%$ to obtain sound reduction well within the accuracy to be expected of the method of estimating aircraft noise presented in this report. For all materials having an absorption coefficient greater than .44 this degree of accuracy can be obtained by assuming an absorption coefficient of .72 since the coefficient will never exceed unity.

Examination of published data on commercial acoustical materials (See Ref. 7) shows none that have lower absorption coefficients than .44 at frequencies above 500 cps, provided the thickness is at least 1/2 inch. However, there are many airplane wall areas which cannot be covered by acoustical material (e.g., windows) and in these cases the absorption coefficient is frequently less than 0.1 where even the measurement of absorption coefficients to an accuracy of 40% is difficult. However if these areas are not greater than the area treated by acoustical material, the absorption coefficient need not be known within a factor of 150% since the total absorption entering equation (4) is the sum of the contributions from each area and the contribution for untreated areas is considerably less than that for treated areas. Thus it is only necessary to know absorption coefficients nominally for acoustical materials, people, non-porous fabrics and non-porous wood, metal or glass areas. Approximate values are given in Table II. Provided acoustical materials are installed over

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half or more of the surface area of the cabin, use of the values in Table II should give a satisfactory estimate of the total absorption. In considering the area of acoustical material, those covered by non-porous fabrics should be excluded and the non-porous fabric coefficient used instead of the coefficient for the acoustical material.

In considering transmission coefficients there are two types of structure of importance in aircraft. The first is a single panel of a non-porous fabric, metal, wood, glass or like material. The second is a multiple structure composed of a non-porous panel to which has been added various layers of acoustical materials and non-porous fabrics.

The important parameter for estimating transmission coefficients of single non-porous panels at frequencies above 600 cps. is the surface density. Figure 10 illustrates this simple relation. It is sometimes more useful to know the attenuation of the structure which is defined as $10 \log \left(\frac{1}{\tau} \right)$ where τ is the transmission coefficient. Figure 11 shows the relation between attenuation and surface density for a single non-porous panel.

The second type structure shows large differences in the transmission coefficient for different acoustical materials. However, one of the lightest weight materials for a given transmission coefficient is that covered by Specification MIL-B-5924(USAF) Type 1. In view of the premium on weight in most aircraft, this material has become widely used and therefore consideration of transmission will be restricted to structures using it. In application insulating blankets are frequently used consisting of layers of the acoustical material separated by septa of non-porous fabrics and a porous trim covering. Provided the total weight of all septa involved does not exceed the weight of the acoustical material, the transmission coefficient, at a given frequency above 600 cps, depends only on the sum of the septa and acoustical material surface densities and the surface density of the dural panel to which the blanket is applied. The porous trim cloth contributes nothing to the transmission coefficient and is used only as a protection for the blanket. Several structures using this type of blanket are illustrated in Figure 12 and sound transmission coefficients and attenuations are shown in Figures 13 and 14 as a function of the surface density of the septa plus acoustical material.

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F. WEIGHT NECESSARY TO SOUNDPROOF TO PREDETERMINED LEVELS

From methods given in previous sections of this report it is possible to determine the external aerodynamic noise levels and the noise reduction afforded by the skin and interior insulation. The problem now is to determine the amount of soundproofing necessary to insulate the interior of the airplane to certain specified levels. Only a rough approximation can be given as answer to this question unless considerable detail is known about the airplane. However such an approximation can be obtained quite readily from a knowledge of the indicated airspeed. This approximation assumes that the airplane cabin has uniform walls and is immersed in a uniform external noise field. It further assumes that the skin is dural with an average thickness of 0.02 inch. Under these assumptions the external aerodynamic noise in three octaves has been plotted against airspeed as in Figures 15, 16, and 17. From this band the sound reduction calculated by the methods previously developed have been subtracted for three different soundproofing structures as shown at the top of these figures and the resulting bands giving the expected internal noise levels, are shown as the three lowest in the figures. These structures are assumed made of batting conforming to Specification MIL-B-5924(USAF) Type I and with non-porous septa between layers of batting about equal in surface density to that of the batting. The heavy line on the right represents the 0.02 inch dural skin and the surface densities represent the weights of the batting plus septa only, omitting the skin and any trim covering necessary for protection of the batting. To determine which structure will give the desired noise level it is only necessary to determine in which band the point defined by the desired level and known airspeed falls. This band then determines the structure.

It is of interest to investigate the fraction of airplane weight required for soundproofing. The interior area of aircraft available for installation of soundproofing depends on the compartment arrangement and the area of windows, etc. Figures 18 and 19 are plots of the average available areas as a function of total empty fuselage weight for cargo and bombardment type airplanes. From a knowledge of this area and of the surface density of the soundproofing structure the total weight of sound proofing required is then available. For cargo aircraft the use of the heaviest treatment considered in Figures 15, 16, and 17 gives the total weight of soundproofing as about 0.5 percent of the empty weight of the airplane.

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The foregoing results can be corrected for the effects produced when the skin thickness is different from that assumed and when transparent areas prevent insulation of the entire interior of a compartment. The effects of these factors will be shown by the following example.

As a first approximation, it is assumed that the skin of the airplane is uniform and that a uniform soundproofing treatment will be applied to the interior surface. In making this assumption it is necessary to keep in mind however that any non-treated areas of the inclosure will tend to increase the noise level. Therefore a blanket should be chosen which will give an attenuation somewhat more than the noise reduction required. In addition, since the absorption coefficient never exceeds 1, the total noise reduction will be less.

Given the following details for a cargo type airplane, the amount of soundproofing necessary will be determined to meet these required noise levels:

600-1200 cps - 95db; 1200-2400 cps - 85 db; and 2400-9600 cps - 75 db.

Airplane Details: Fuselage - Empty: Weight - 4500 lbs
Average skin thickness - .040 inch
Window surface density - 1#/ft²
Indicated airspeed - 250 mph
Porous trim cloth.

From Figures 15, 16, and 17 it is seen that the exterior aerodynamic noise in the above respective frequency bands is approximately 123, 125, and 124 db. The noise reduction required by the inclosure in these frequency bands is then 28, 40, and 49 db.

From Figure 18, which gives the results of a statistical survey of the fuselage interior surface area versus the total fuselage empty weight of cargo airplanes, it is possible to approximately determine the interior surface area of the fuselage of this airplane. Figure 19 gives this comparison for bomber aircraft. If the actual interior area of the airplane is known it would be better to use the actual value for these calculations. Since the interior area is not specifically known, it is estimated from Figure 18 that the available area for insulation is 1250 square feet, transparent area is about 290 square feet. Assuming that the total 1540 feet of the fuselage interior may be covered with soundproofing thus making it a uniform inclosure, it is seen from Figure 14 that a blanket which has a surface density of .1 pound per square foot gives attenuations of 32, 45, and 61 db or from Figure 13 the transmission coefficients are .00063, .000032, and .00000079 respectively.

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123 124 125
- 28 - 40 - 49

95db 85db 75db

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From Section B the noise reduction, assuming the absorption coefficient equals .7, .8 and .9, is:

$$600-1200 \text{ cps frequency band N. R.} = 10 \log \left(1 + \frac{.7}{.00063} \right) = 30.5 \text{ dB}$$

$$1200-2400 \text{ cps frequency band N. R.} = 10 \log \left(1 + \frac{.8}{.000032} \right) = 44 \text{ dB}$$

$$2400-9600 \text{ cps frequency band N. R.} = 10 \log \left(1 + \frac{.9}{.00000079} \right) = 60.5 \text{ dB}$$

It is seen from the above values that the noise reduction afforded by the inclosure with the insulation installed is still somewhat below that required to meet the specified levels. There still remains however a correction to be made for the 290 square feet of transparent area.

Figure 20 gives the correction for the untreated areas. This figure was derived by assuming that

$$- \text{N. R.} = 10 \log \frac{T}{A} \tag{6}$$

From Section B

$$A = S_u \alpha_u + S_c \alpha_c \approx S_c \alpha_c \tag{7}$$

$$T = S_u \tau_u + S_c \tau_c \tag{8}$$

where the subscripts u and c designate the covered and uncovered portions of the inclosure. $S_u \alpha_u$ will be small, if more than 1/2 of the inclosure is treated, and therefore may be neglected.

By substituting equations 7 and 8 into 6, the following relationship is obtained:

$$\text{N. R.} = 10 \log \frac{\alpha_c}{\tau_c} - 10 \log \left(1 + \frac{S_u \tau_u}{S_c \tau_c} \right) \tag{9}$$

For the case at hand $\frac{S_u}{S_c} = \frac{290}{1250} = .23$

$$10 \log \frac{\tau_u}{\tau_c} = -1 \text{ dB} \quad \text{for the 600 cps frequency band}$$

$$10 \log \frac{\tau_u}{\tau_c} = 6 \text{ dB} \quad \text{for the 1200 cps frequency band}$$

$$10 \log \frac{\tau_u}{\tau_c} = 16 \text{ dB} \quad \text{for the 2400 cps frequency band}$$

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The values of C_u for the transparent areas were obtained from Figure 10.

The corrections for the above respective frequency bands from Figure 20 is then approximately: 1 db, 3 db and 9 db.

The noise reduction for the insulated inclosure is

30.5 - 1 = 29.5 db for the 600-1200 cps frequency band,
44 - 3 = 41 db for the 1200-2400 cps frequency band,
60.5 - 9 = 51.5 db for the 2400-9600 cps frequency band,

The reason for choosing a blanket which has attenuations somewhat larger than the required noise reduction is readily seen from the above example.

The weight expended to insulate the example aircraft is about 125 pounds or 0.5% of the total empty weight of the airplane.

From the above example it is readily apparent the effect that untreated areas have on the noise levels in the inclosure. In many cases where soundproofing is improperly installed or large areas are left untreated, the soundproofing in the inclosure becomes almost totally ineffective and therefore is only "excess baggage". It is really better to install soundproofing of lesser weight uniformly throughout the inclosure than to install heavier soundproofing in a relatively small area.

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G. CONCLUSIONS

1. Adverse effects from noise, suffered by personnel in modern aircraft, are mainly due to that portion of the noise at frequencies above 600 cps.

2. The reduction in noise afforded by sound insulation of a compartment at frequencies above 600 cps can be simply estimated by the method developed in Section B provided the absorption and transmission coefficients of the materials making up the compartment are known.

3. Satisfactory values for the absorption coefficients of materials usually found on the walls of aircraft compartments are given in Table II.

4. When the insulation batting is of the type covered by Specification MIL-B-5924 (USAF) Type I, the transmission coefficients at given frequencies above 600 cps for structures composed of successive layers of batting and non-porous septa are simply related to the surface density of the layers of batting plus septa as shown in Figures 13 and 14.

5. Aerodynamic noise level due to airflow over the fuselage is linearly related to the logarithm of the indicated airspeed to a first approximation as shown in Figures 7, 8, and 9. Changes in fuselage shape and altitude exert a secondary influence.

6. In jet propelled aircraft and in multi-engine propeller driven aircraft aerodynamic noise is usually the predominant type at frequencies above 600 cps and therefore the sound insulation required to reach specified internal levels can be estimated from the results of this report in the early stages of design. In other aircraft types the minimum required sound insulation is usually obtained when estimates are based on the aerodynamic noise levels herein. In this case sources of noise other than aerodynamic must be considered in designing the sound insulation.

7. The heaviest sound insulating treatment herein considered would weigh about 0.5% of the empty weight of the airplane, but even with this amount of insulation the noise levels are quite high for high speed aircraft.

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TABLE I

Legend to Aircraft

Legend	Airplane Model	Airspeed MPH
●	XC-4	50
		70
		90
		110
		130
		150
		120
		127
		135
		135
		142
○	XPBY-1	120
■	XPBY-5A	127
▲	XB-49	135
●	XPB2Y-3	135
△	C-47	142
□	C-53	144
x	PBM-3	150
+	PBM-1	150
■	B-34	150
✕	DC-3B	160
✕	CW-20A	170
△	B-17F	171
✕	XPBM-2	179
✕	B-24D	188
◇	C-119B	200
+	B-25C	213
◆	B-25B	212
○	YC-97	213
◇	F-80	225
		270
		308
		356
		400
●	EB-45A-1	250
		310
		410
△	XB-47	250
		290
		310
		390
		415
+	XF-86	350
		400
		450
		500
		510
◆	B-50D	220

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TABLE II
REPRESENTATIVE ABSORPTION COEFFICIENTS

	600 cps	1200 cps	2400 cps
Acoustical Material	.7	.8	.9
Wood, Glass, Metal	.05	.05	.05
Non-Perous Trim Fabrics	.6	.4	.2
Absorption of Crew and Passengers (Per person)	4	5	6

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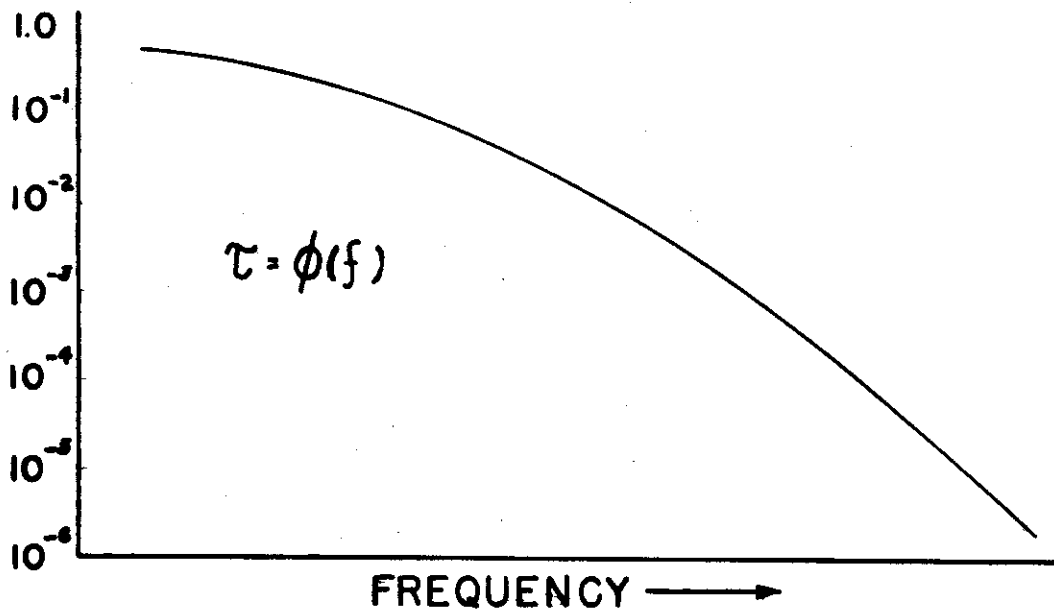
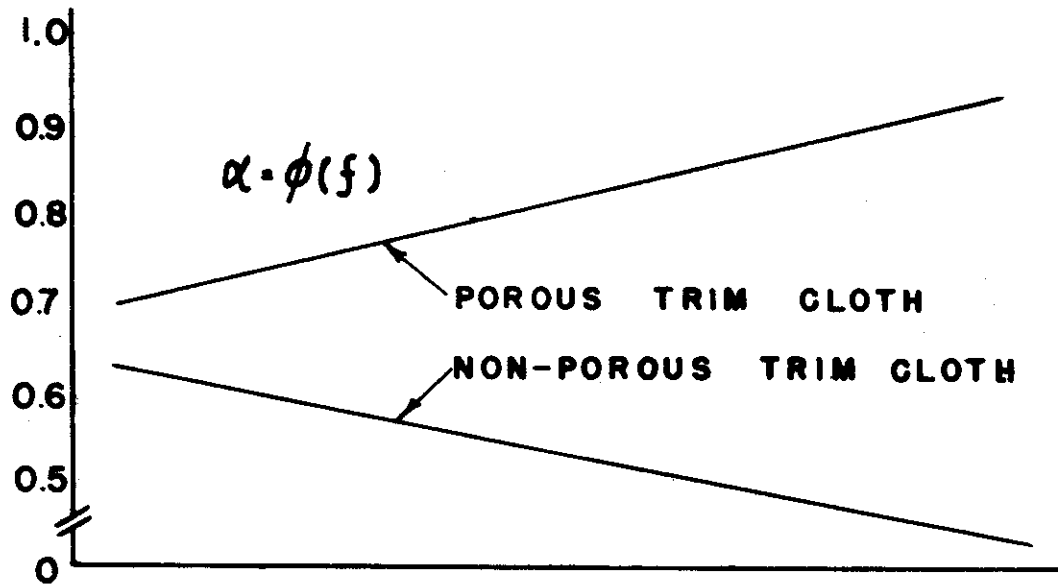


FIGURE I
CHARACTERISTICS OF ABSORPTION
AND TRANSMISSION COEFFICIENTS

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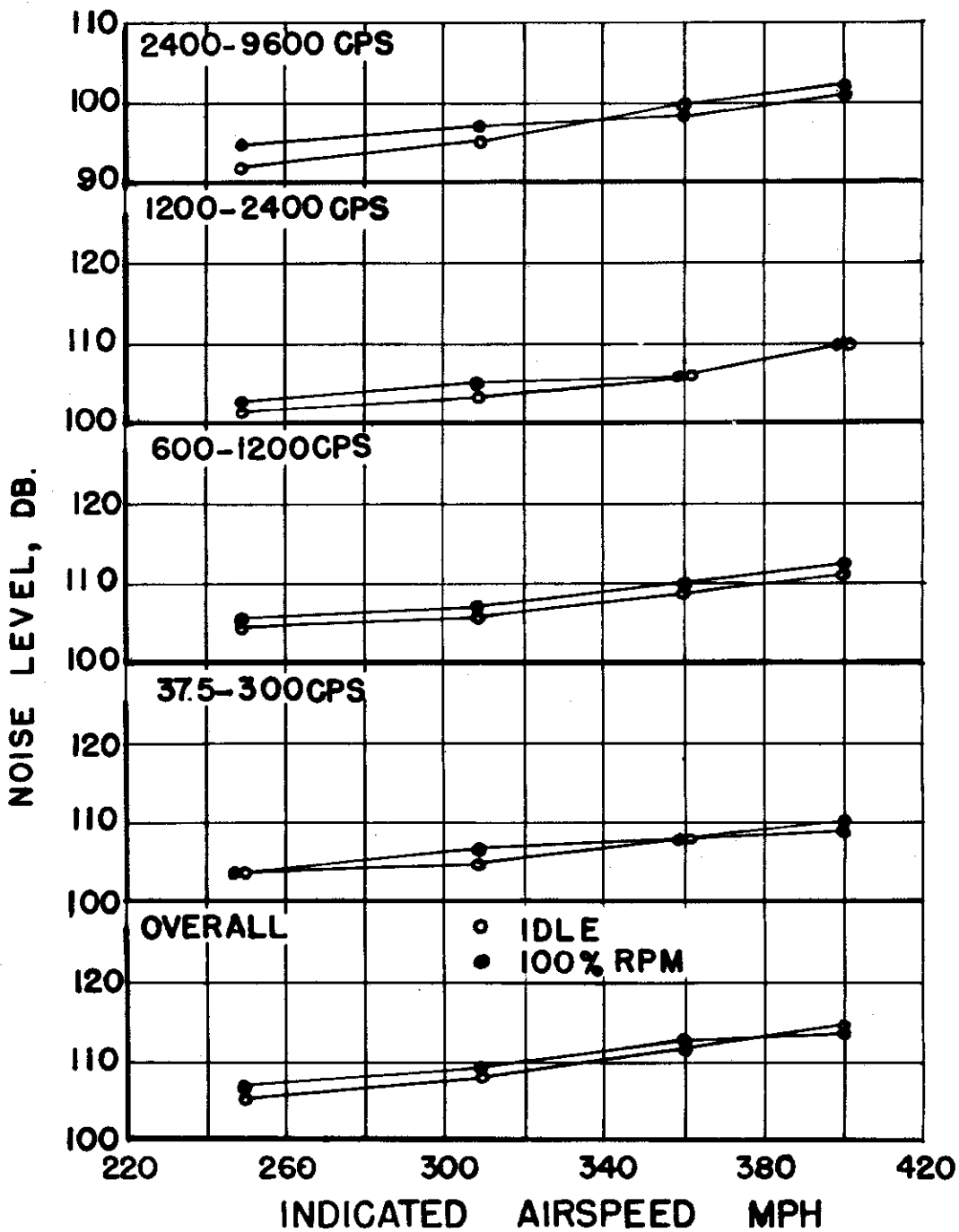
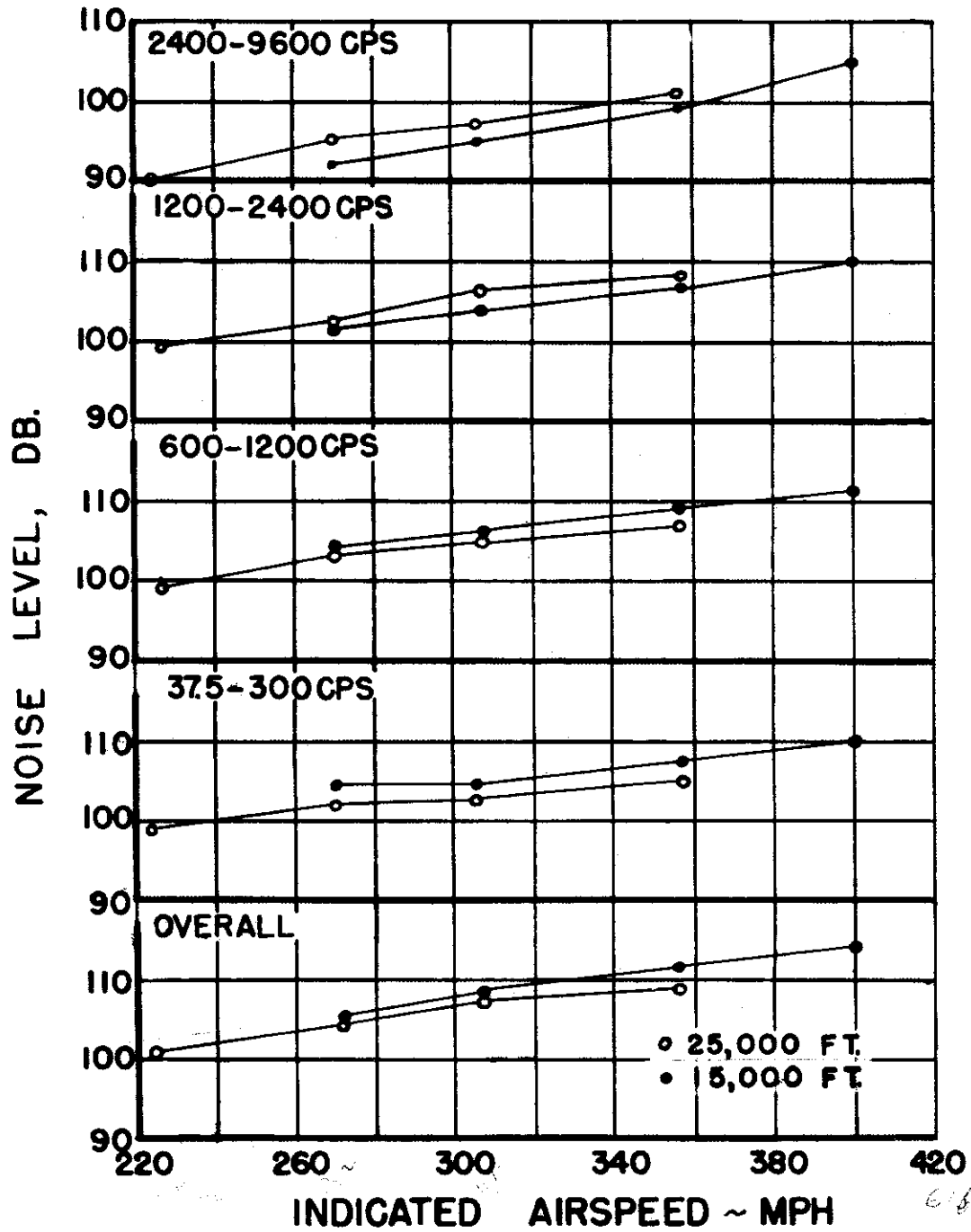


FIGURE 2
EFFECT OF ENGINE ON
CABIN NOISE

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**FIGURE 3
AERODYNAMIC NOISE AT TWO
ALTITUDES**

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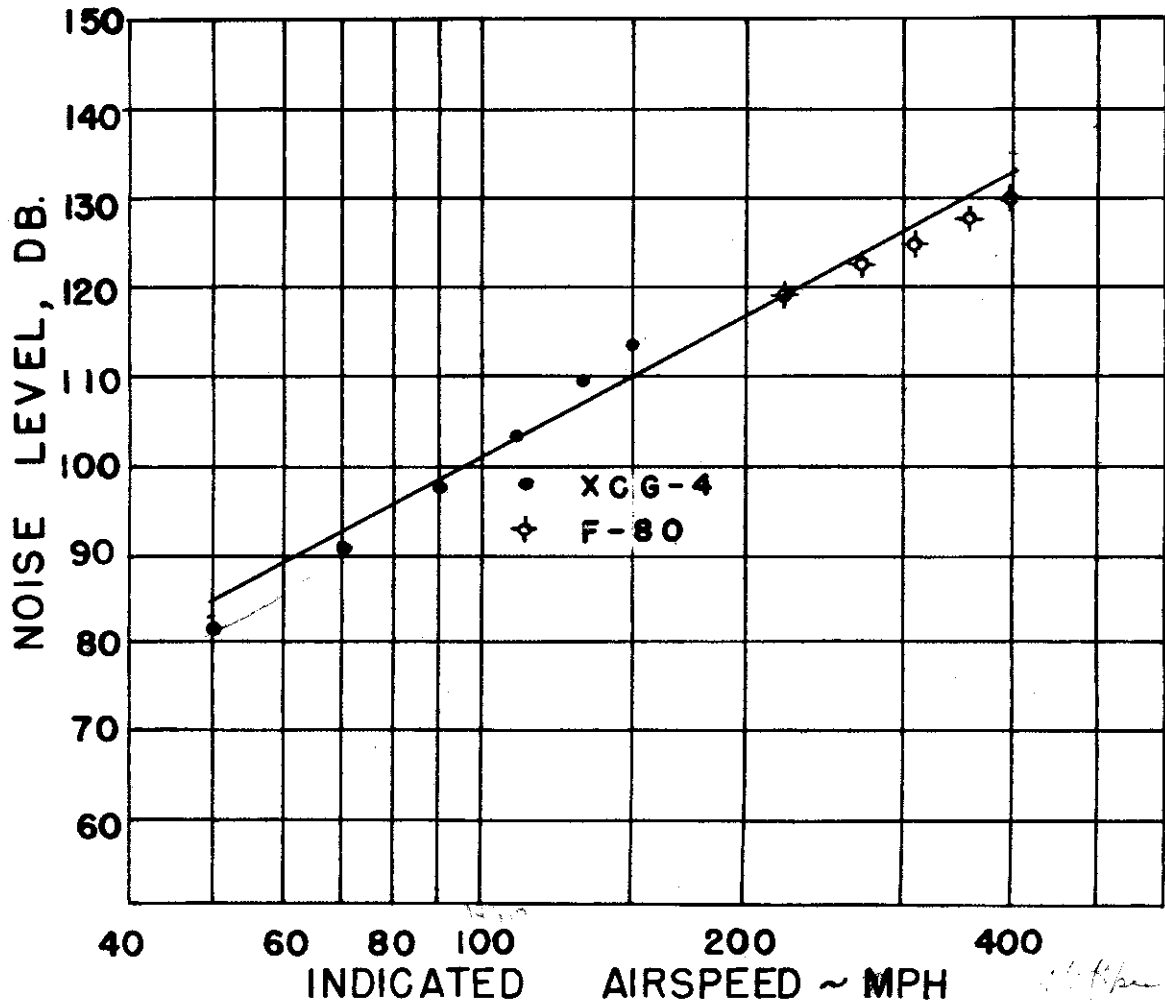


FIGURE 4
AERODYNAMIC NOISE IN THE
600 -1200 CPS FREQUENCY BAND

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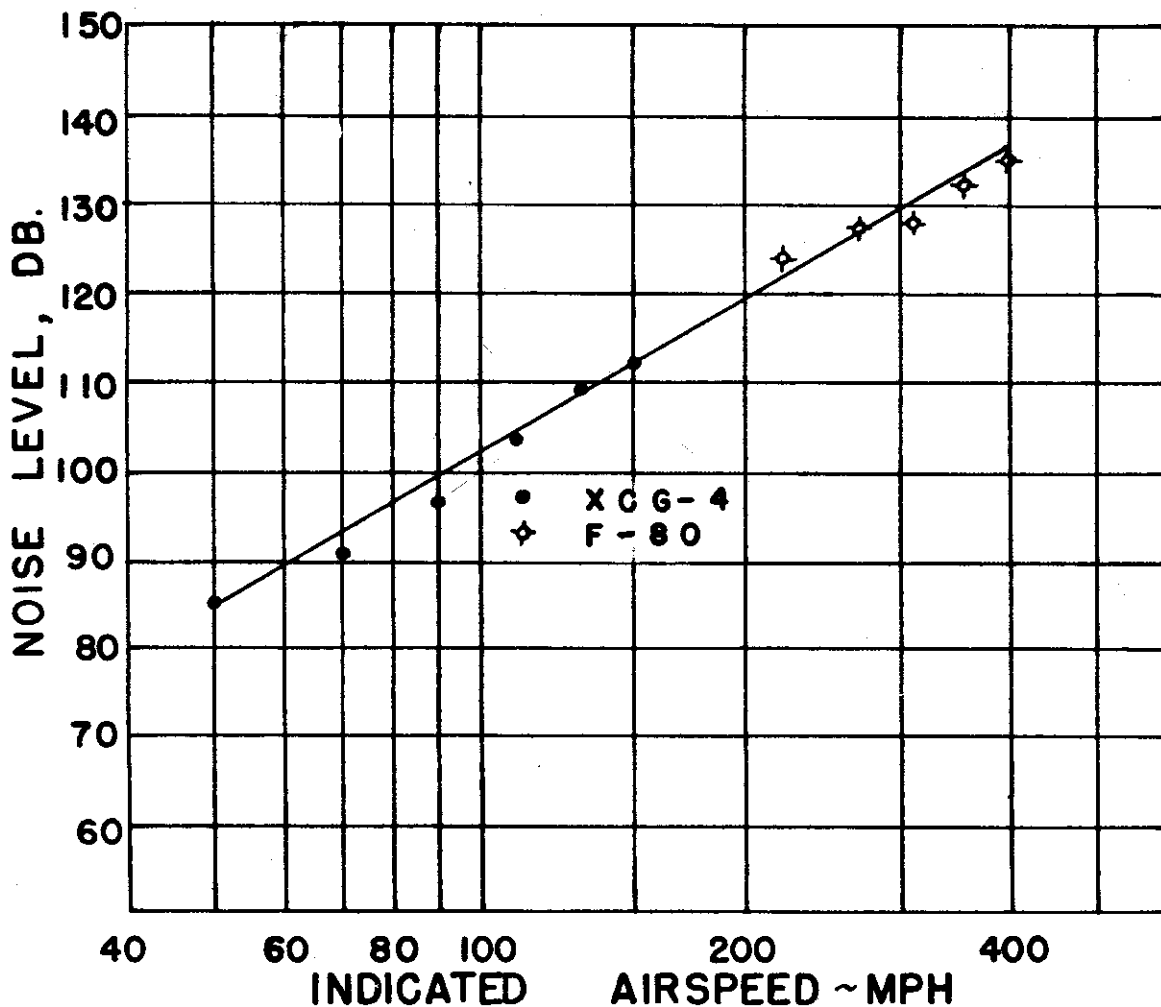
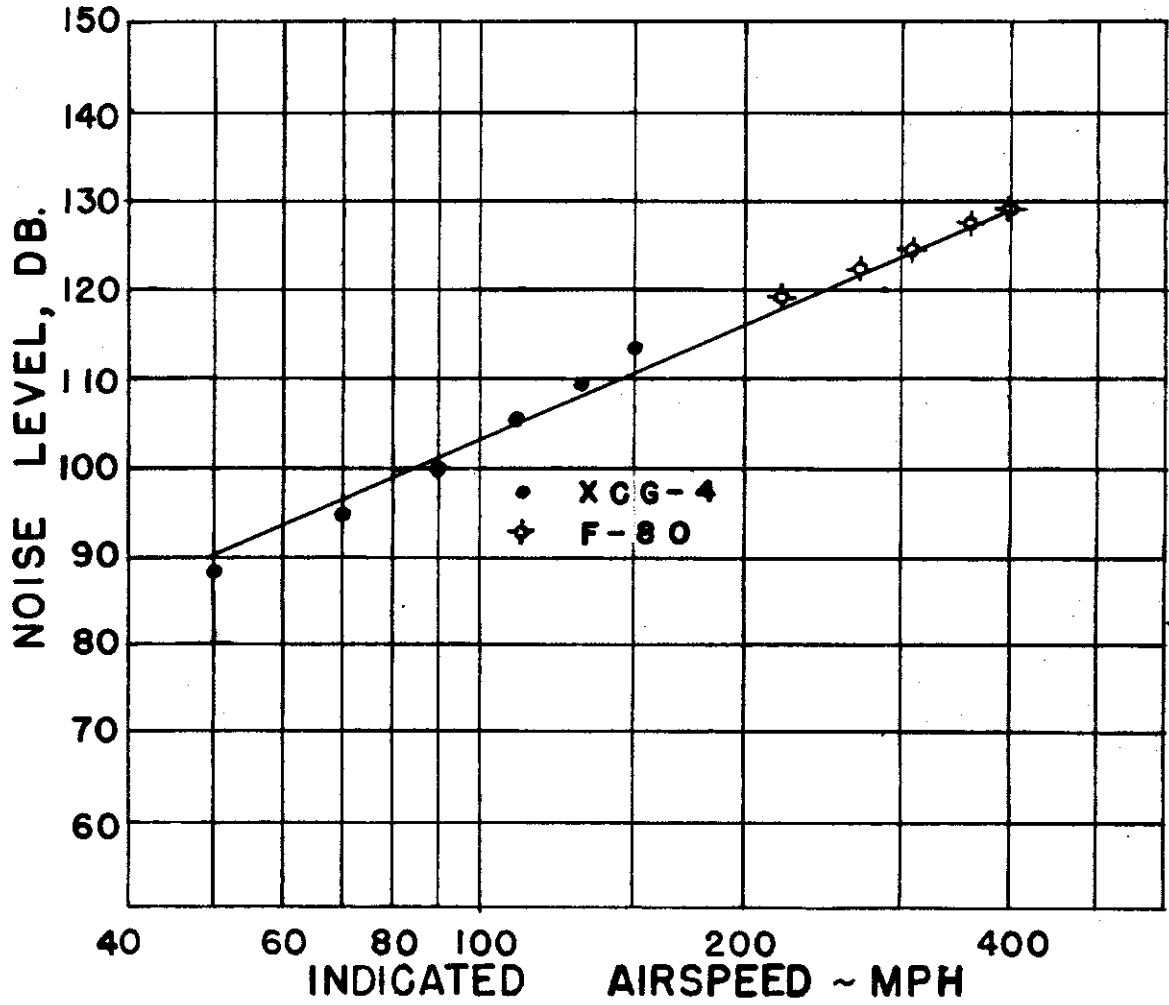


FIGURE 5
AERODYNAMIC NOISE IN THE
1200-2400 CPS FREQUENCY BAND

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**FIGURE 6
AERODYNAMIC NOISE IN THE
2400-9600 CPS FREQUENCY BAND**

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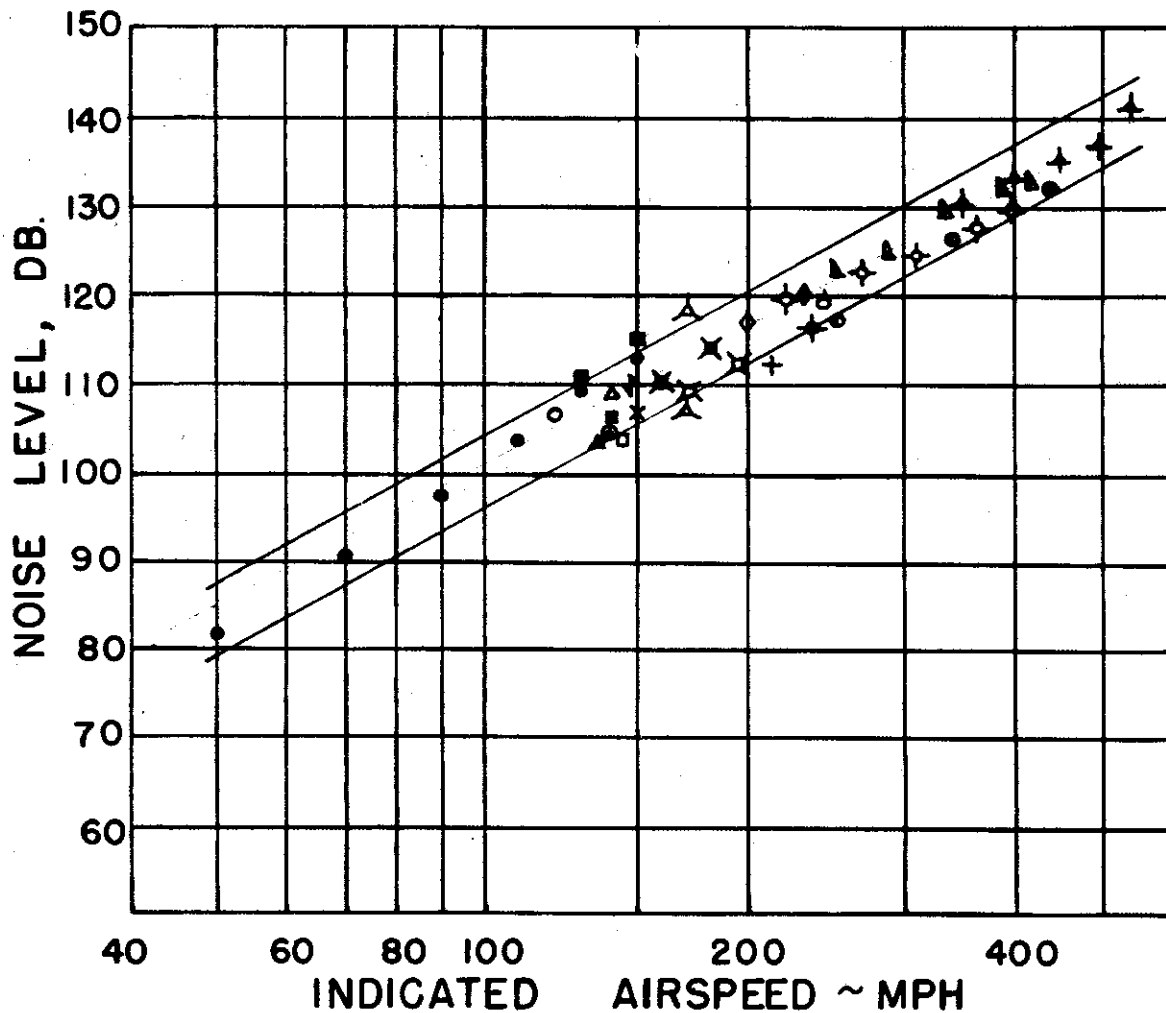


FIGURE 7
OUTSIDE NOISE LEVEL IN THE
600 - 1200 CPS FREQUENCY BAND

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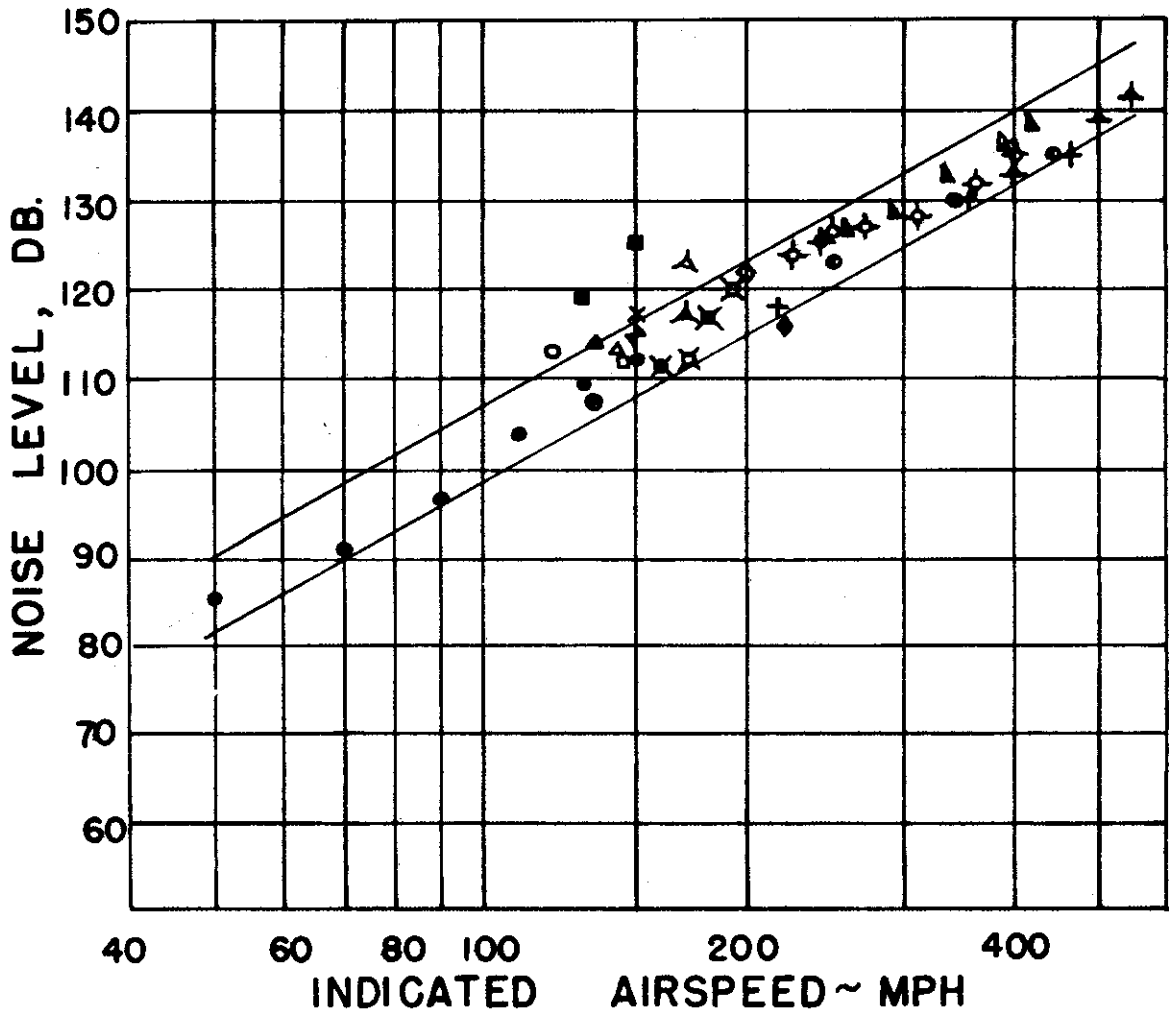


FIGURE 8
OUTSIDE NOISE LEVEL IN THE
1200-2400 CPS FREQUENCY BAND

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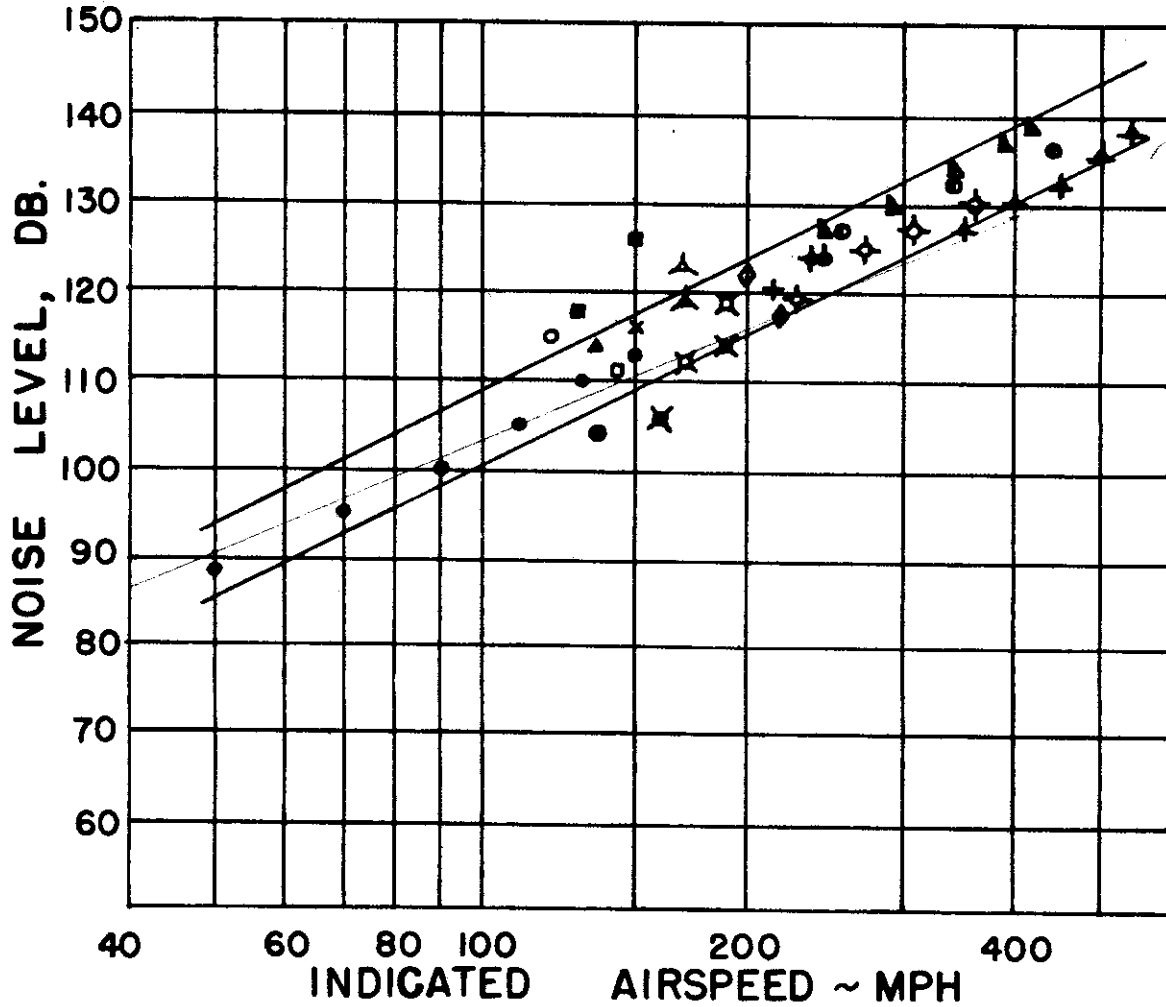
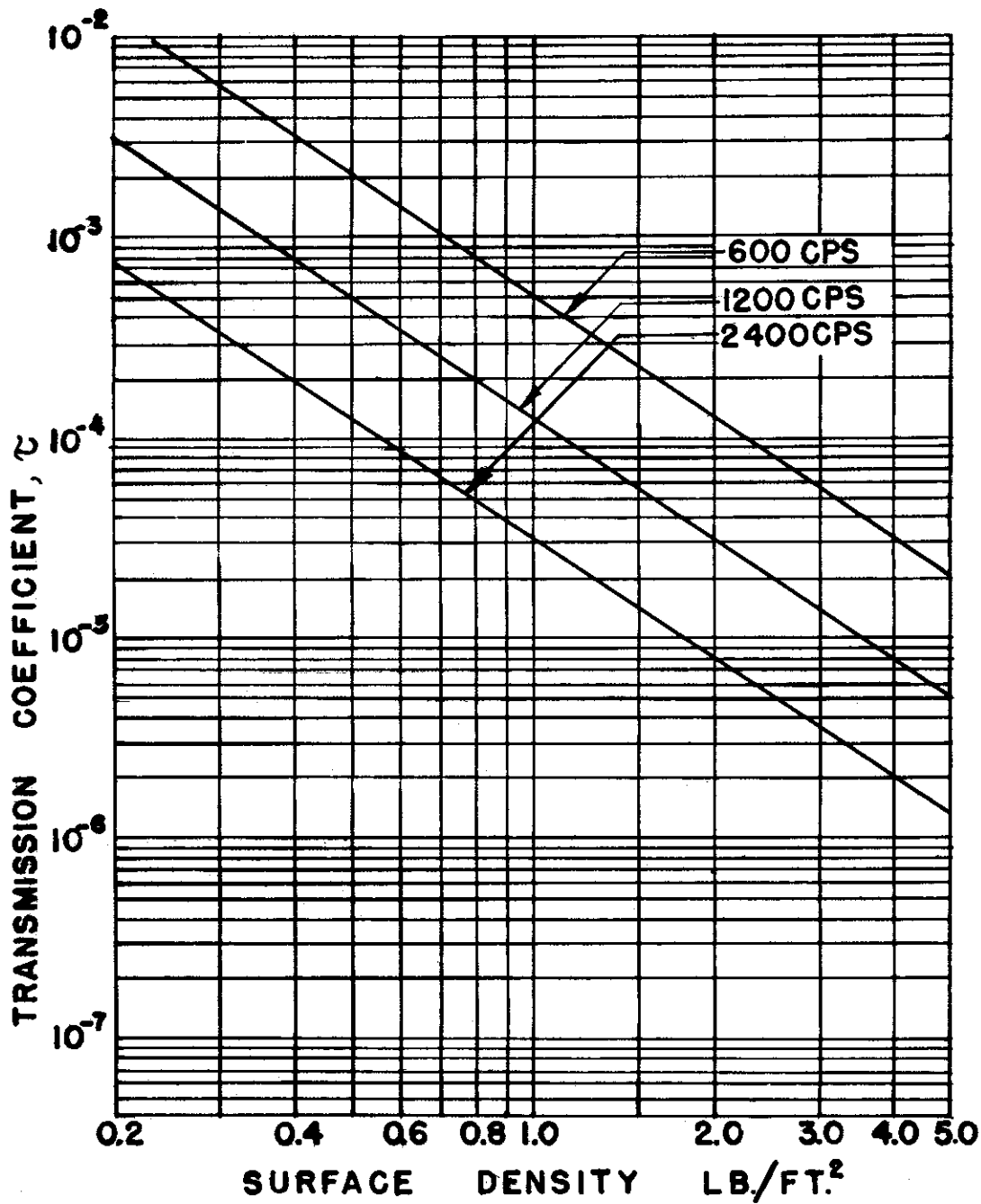


FIGURE 9
OUTSIDE NOISE LEVEL IN THE
2400-9600 CPS FREQUENCY BAND

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**FIGURE 10
TRANSMISSION COEFFICIENT OF
IMPERVIOUS SEPTUM**

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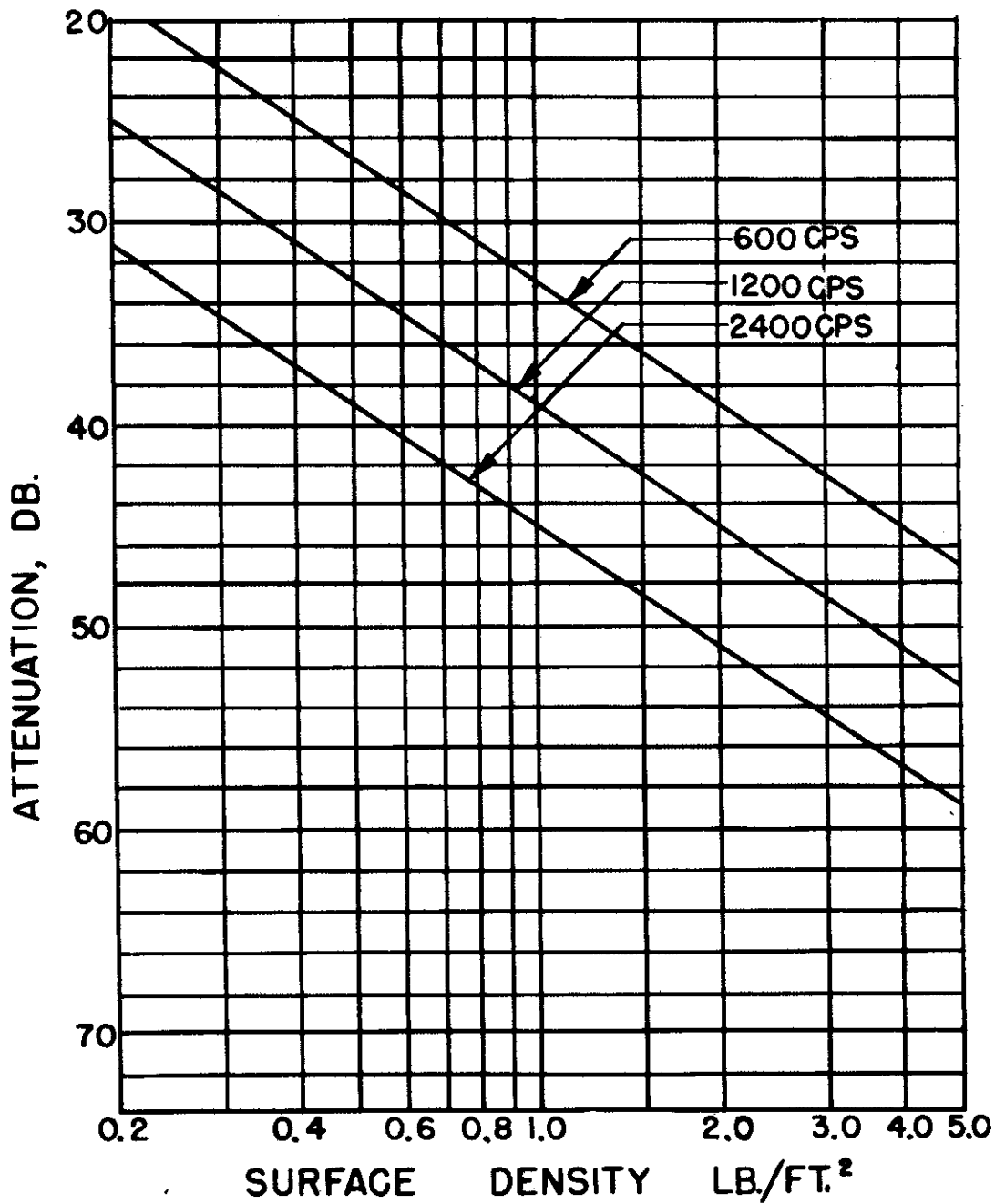
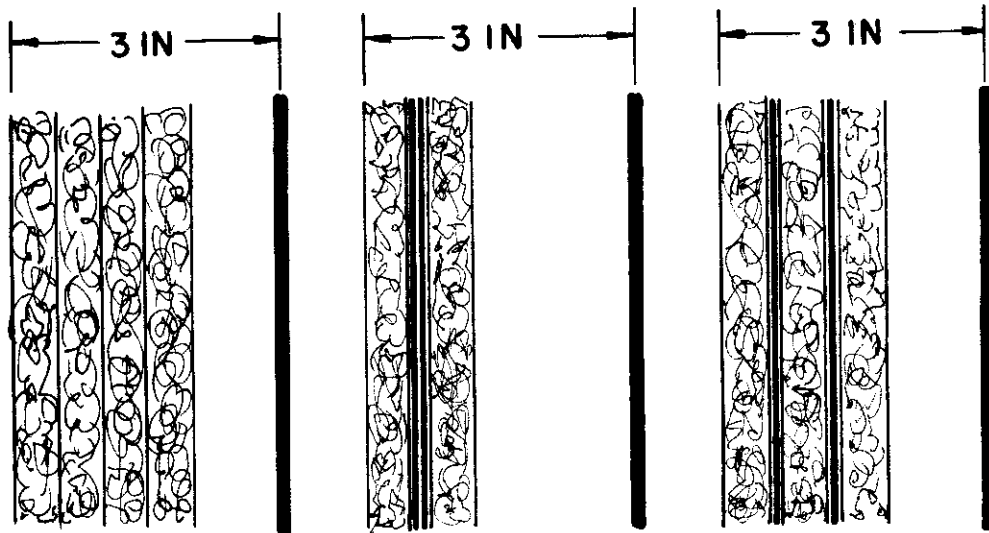


FIGURE II
ATTENUATION OF A SINGLE
IMPERVIOUS SEPTUM

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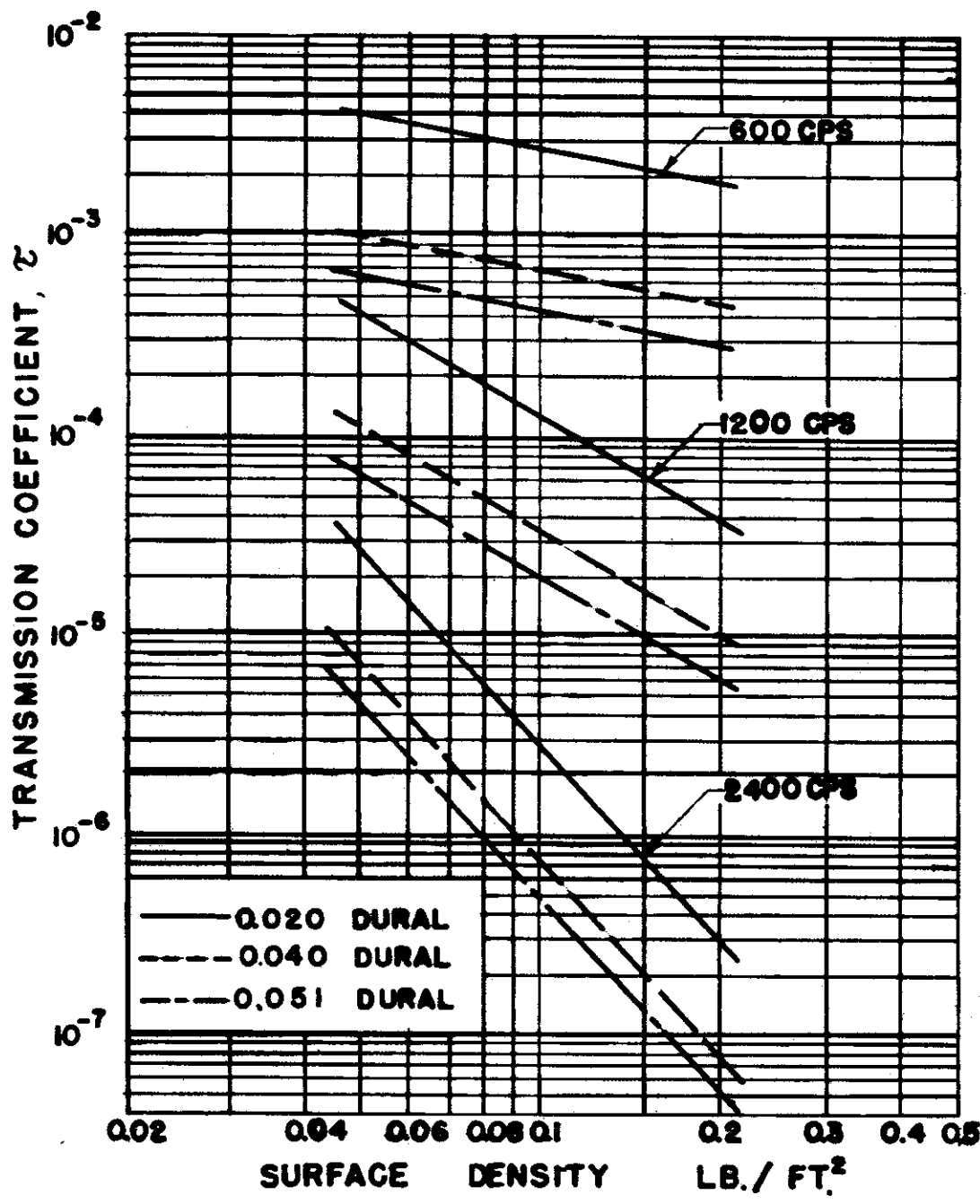


———— DURAL FUSELAGE WALL
———— 0.025 LB/FT² SEPTUM
[Pattern] INSULATION, MIL-B-5924 TYPE I

FIGURE 12
TYPICAL SOUNDPROOFING ELEMENTS
AND CONSTRUCTIONS

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**FIGURE 13
TRANSMISSION COEFFICIENT OF
SOUNDPROOFING BLANKETS**

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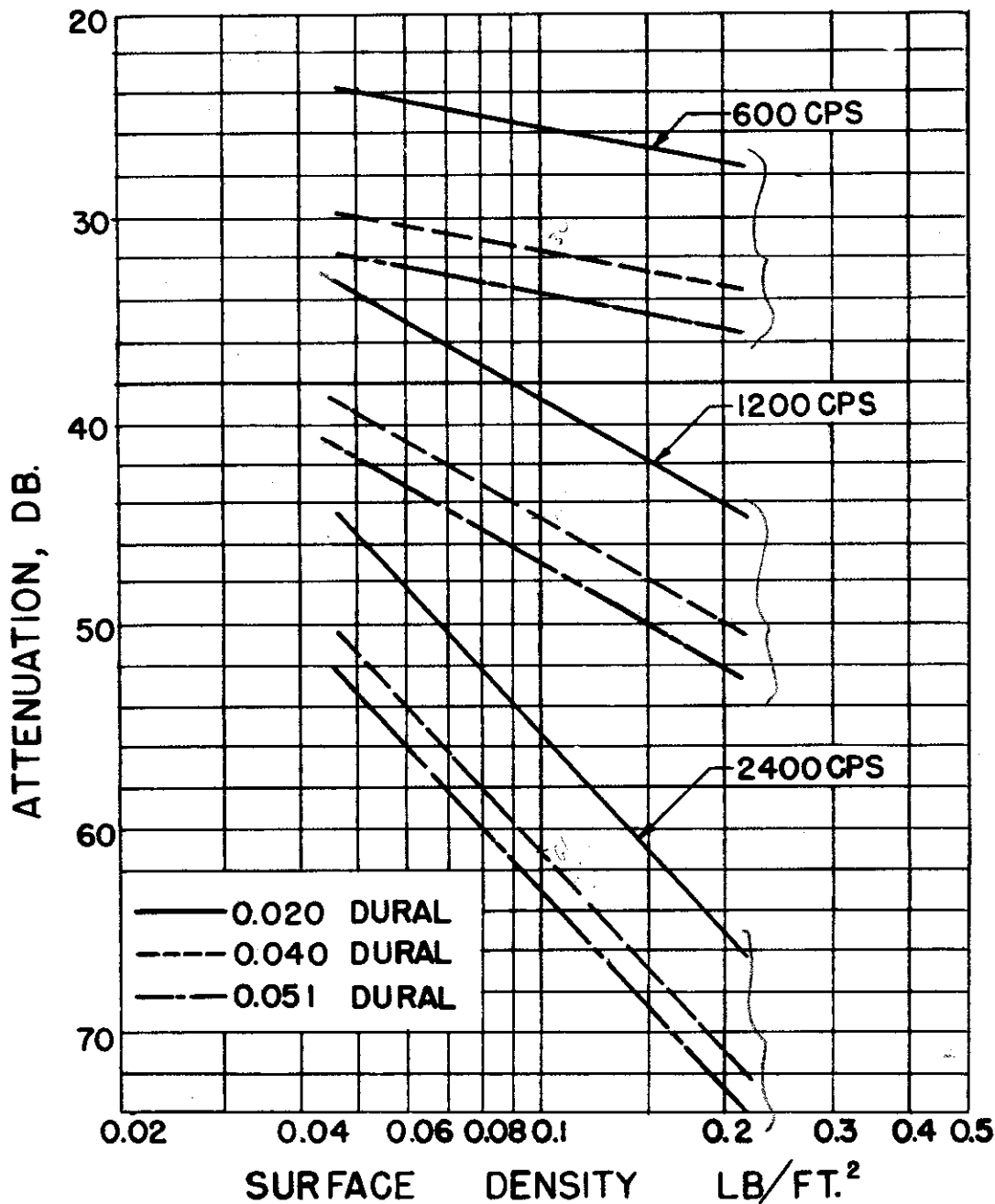


FIGURE 14
ATTENUATION OF SOUNDPROOFING
BLANKET CONSTRUCTIONS

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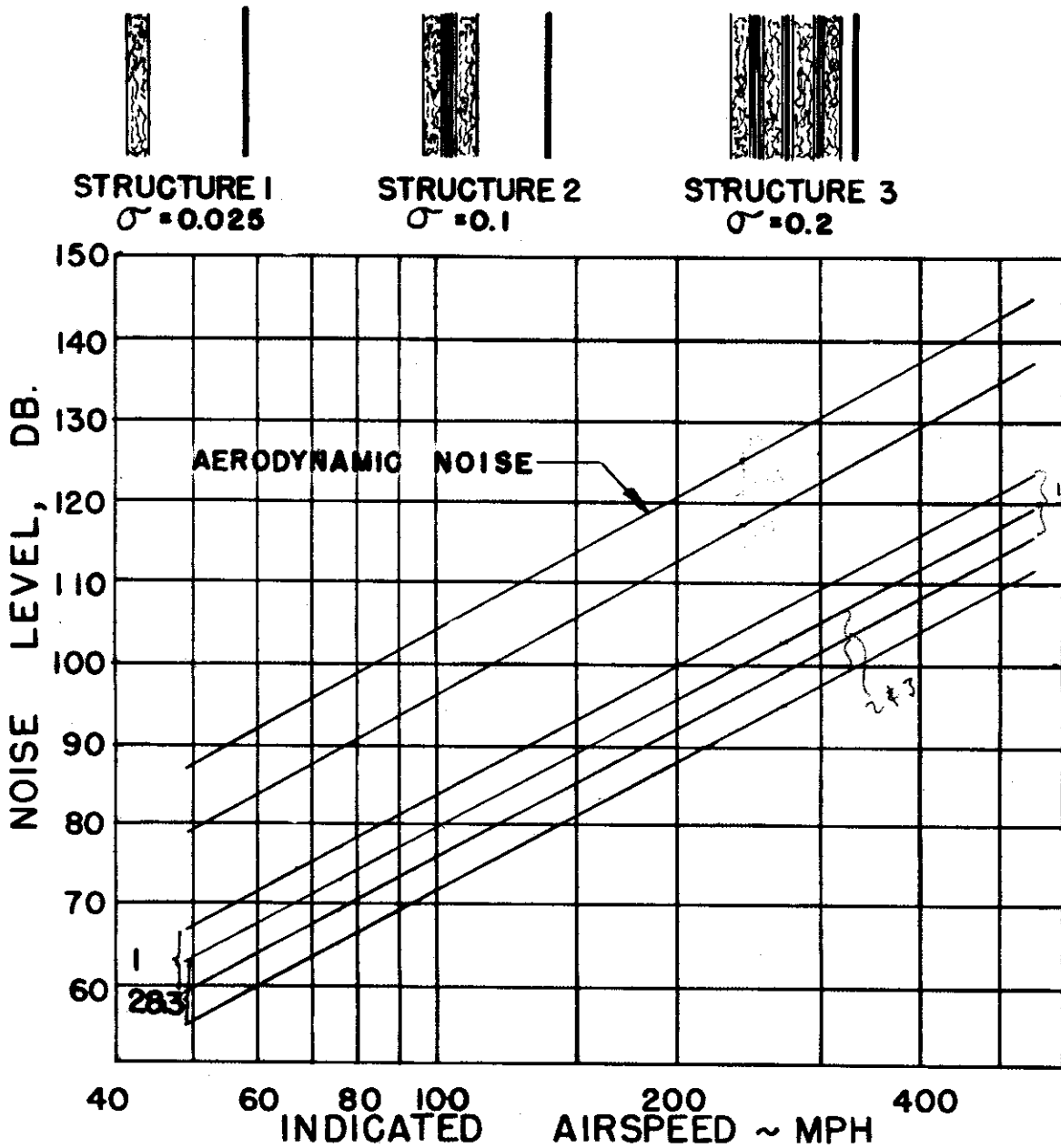


FIGURE 15
EFFECT OF SOUNDPROOFING WEIGHT
ON OUTSIDE NOISE LEVEL IN THE
600-1200 CPS FREQUENCY BAND

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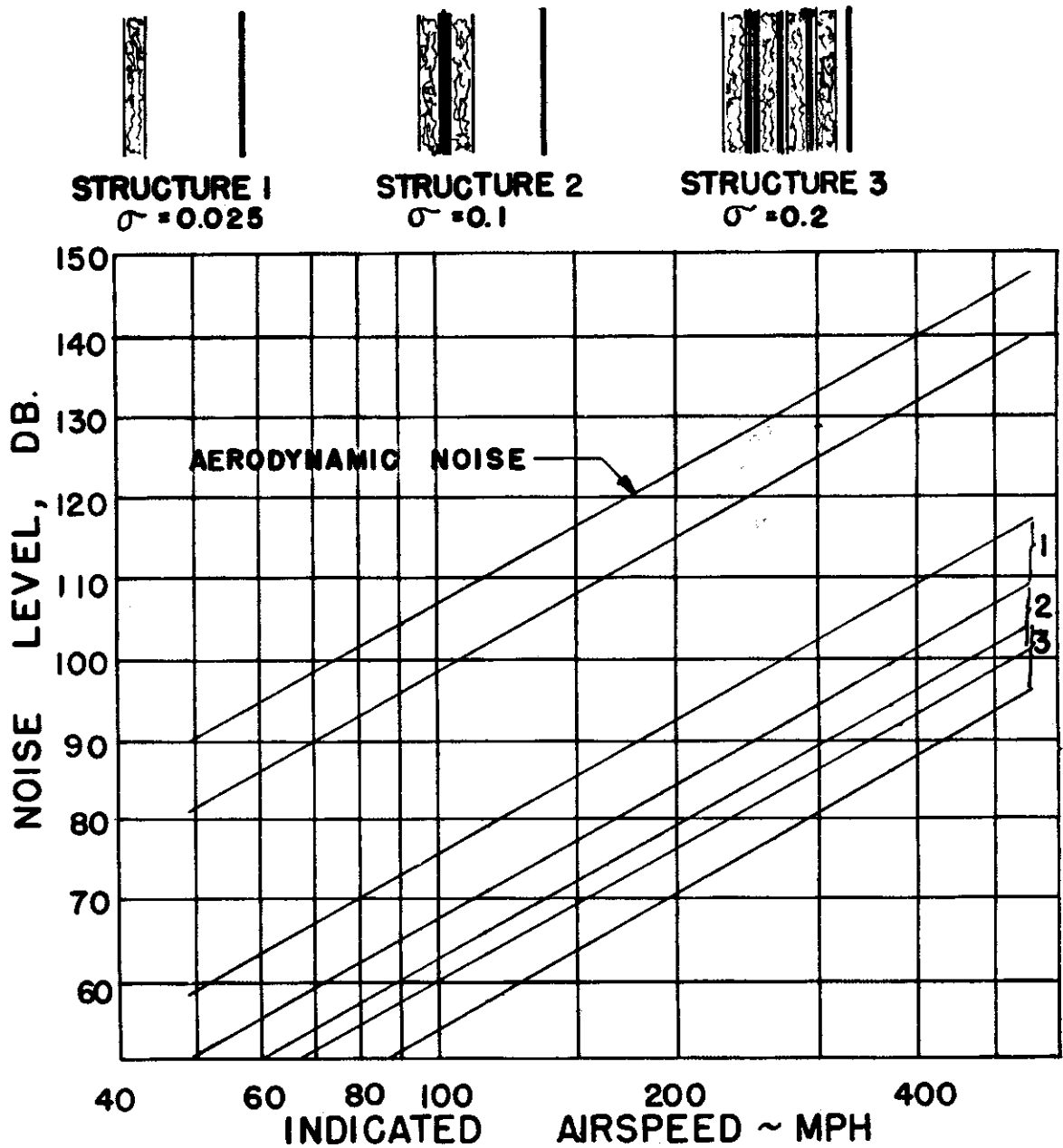


FIGURE 16
EFFECT OF SOUNDPROOFING WEIGHT
ON OUTSIDE NOISE LEVEL IN THE
1200-2400CPS FREQUENCY BAND

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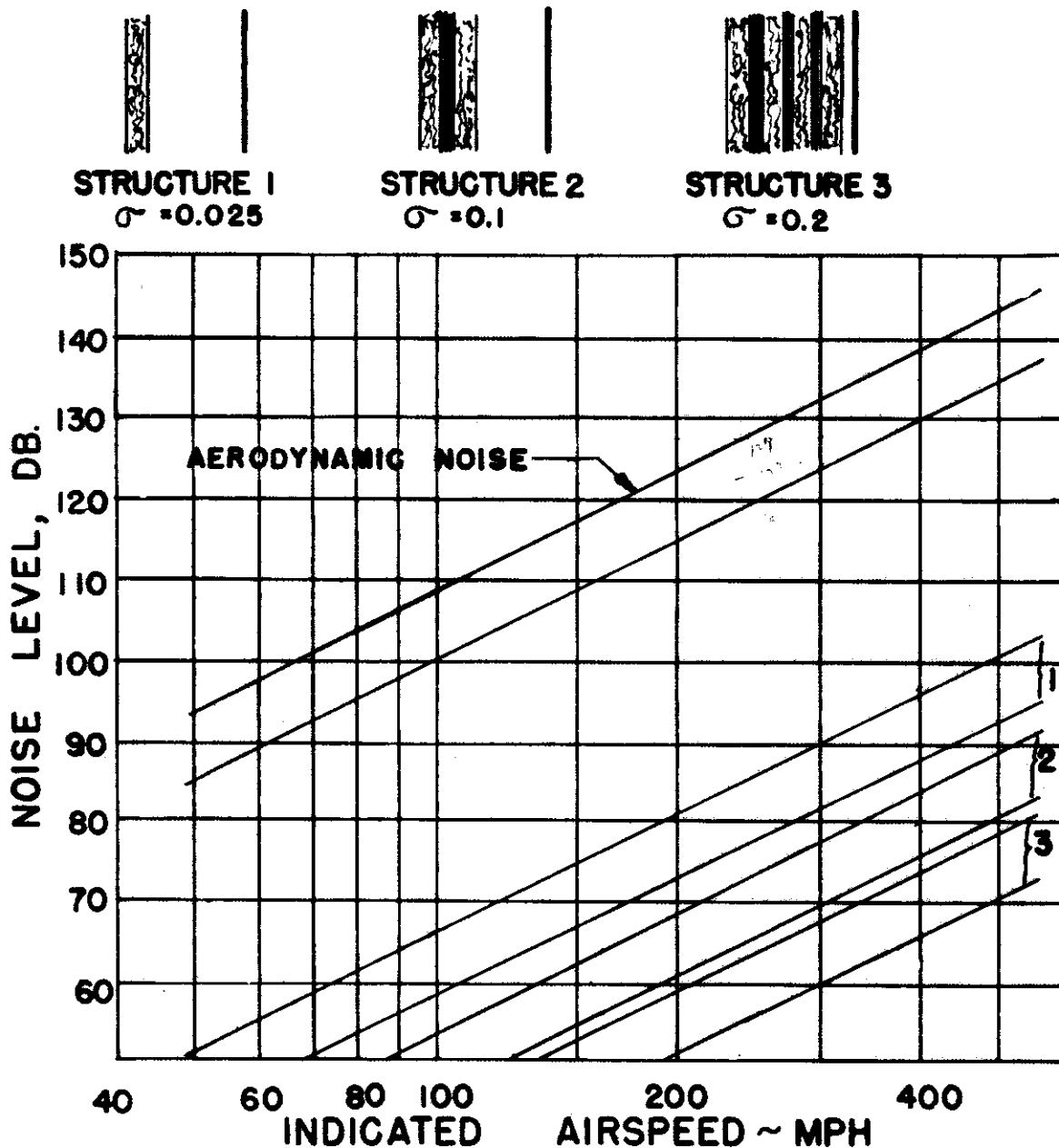
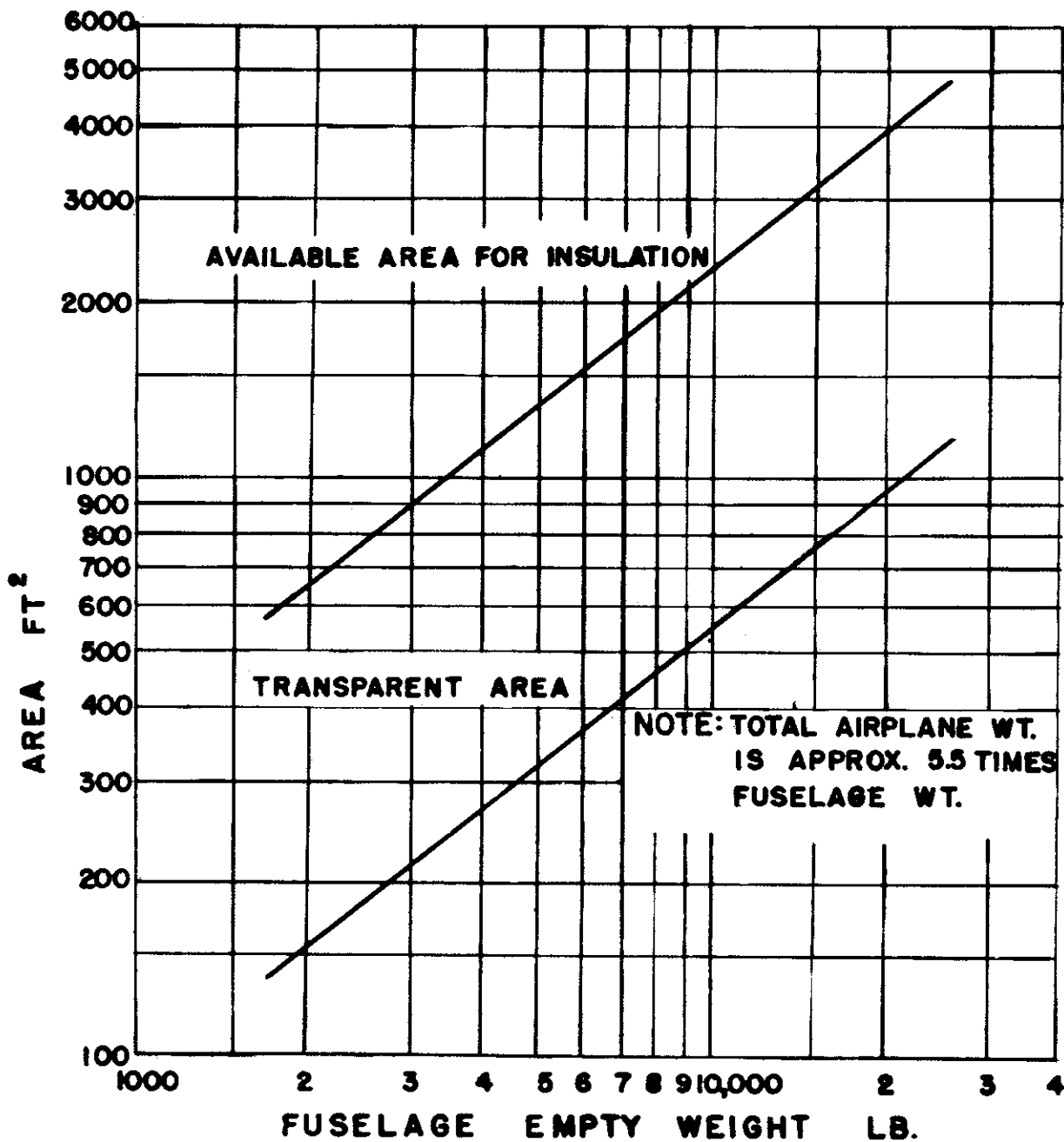


FIGURE 17
EFFECT OF SOUNDPROOFING WEIGHT
ON OUTSIDE NOISE LEVEL IN THE
2400-9600 CPS FREQUENCY BAND

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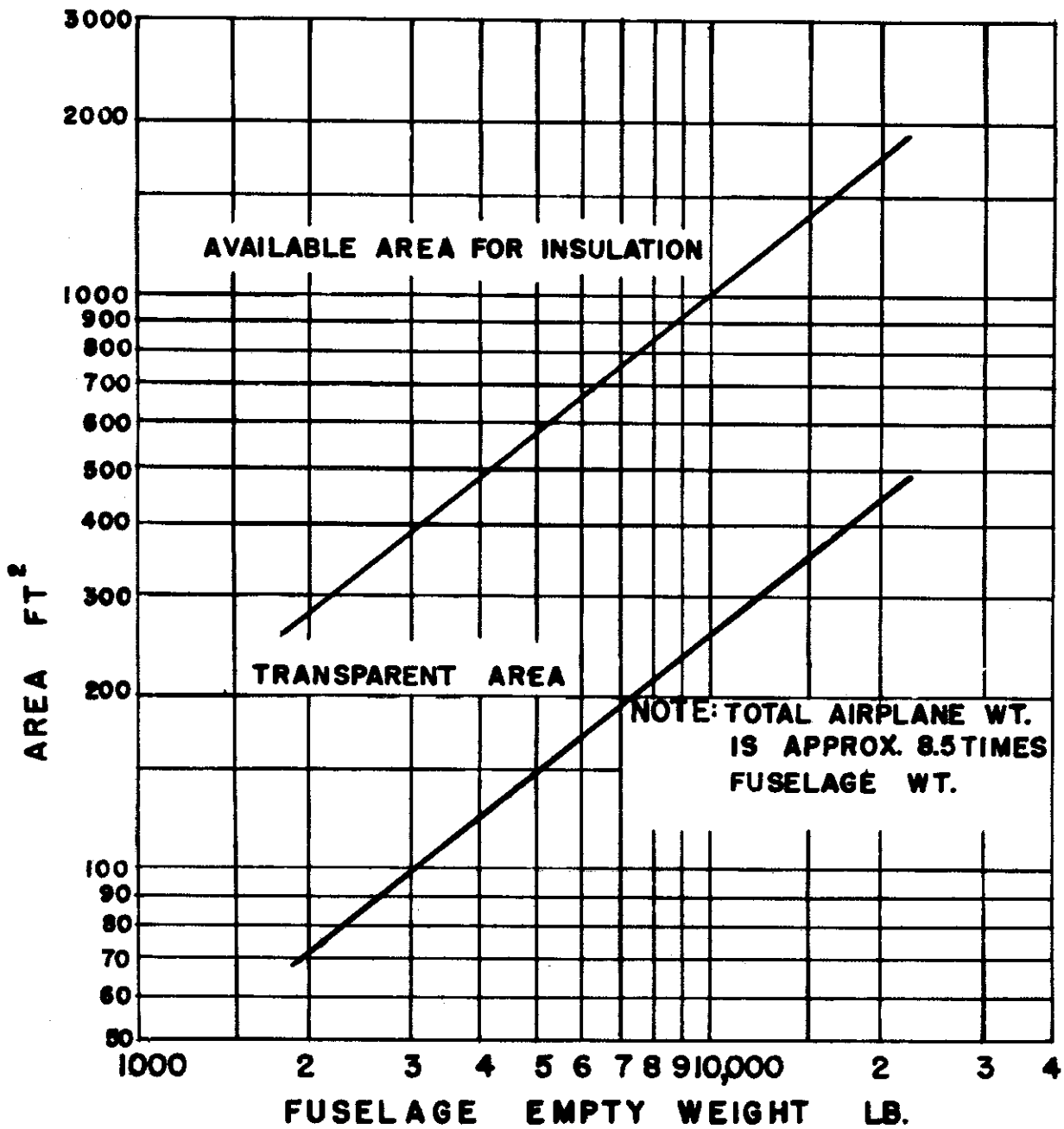
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**FIGURE 18
CARGO AIRCRAFT, INTERIOR
SURFACE AREA**

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**FIGURE 19
BOMBER AIRCRAFT, INTERIOR
SURFACE AREA**

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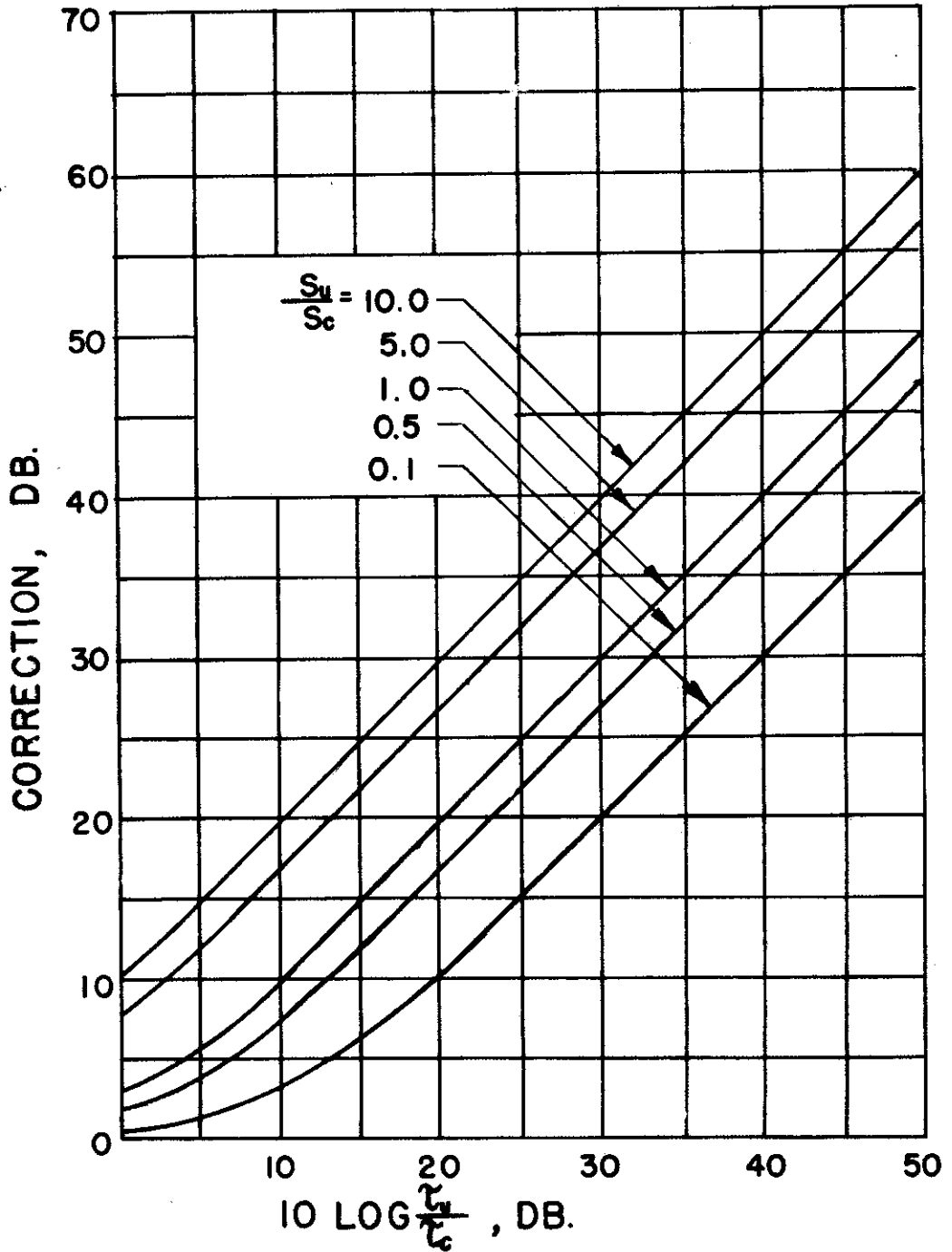


FIGURE 20
CORRECTION FOR PARTIAL
COVERAGE

~~CONFIDENTIAL~~

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