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COMPUTER METHOD FOR DESIGN OF ACOUSTIC LINERS FOR TURBOFAN ENGINES

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16. Abstract

A computer-oriented design procedure for the specification of acoustic liners for turbofans is presented. The method begins with an estimate of the noise generated by a turbofan engine. This estimate is based upon existing information in the literature. The generated source spectrum combined with the results of psychoacoustics leads to a target attenuation spectrum. The liner is designed to meet the target attenuation spectrum in a least squares sense by using the results from an empirically modified theoretical acoustic propagation analysis, together with an empirical impedance model. An example is carried through the discussion in order to demonstrate the method. A limited amount of data are presented to illustrate the comparison between estimate and experiment.

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COMPUTER METHOD FOR DESIGN OF ACOUSTIC LINERS FOR TURBOFAN ENGINES

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SUMMARY

A design package is presented for the specification of acoustic liners for turbofans. An estimate of the noise generation is made based on modifications of existing noise correlations, for which the inputs are basic fan aerodynamic design variables. The method does not predict multiple pure tones. A target attenuation spectrum is calculated that is the difference between the estimated generation spectrum and a flat annoyance-weighted goal attenuated spectrum. The target spectrum is combined with a knowledge of acoustic liner performance as a function of the liner design variables to specify the acoustic design. The liner design method at present is limited to annular duct configurations. The detailed structure of the liner is specified by combining the required impedance (which is a result of the previous step) with a mathematical model relating impedance to the detailed structure. The design procedure is developed for a liner constructed of perforated sheet placed over honeycomb backing cavities.

A sample calculation is carried through the report in order to demonstrate the design procedure, and experimental results presented show good agreement with the calculated results of the method.

INTRODUCTION

The reduction of aircraft engine noise by installing acoustically treated surfaces inside the engine nacelle has become accepted practice with the advent of current generation aircraft. For example there is acoustic treatment in the engine inlet ducts of the wide-body transports in production. Such treatment is installed primarily for the reduction of tone and broad band noise generated by the fan. As noise regulations for new certifications become increasingly restrictive, additional suppression will be required. One of the ways to accomplish additional suppression is to introduce acoustically treated rings in inlets and exhausts.

This report presents a procedure, in the form of a computer program, to design acoustic treatment installations for annular ducts. This design procedure is particularly convenient because it permits the methodical examination of alternative choices of treatment for noise reduction. Such choices as number of splitter rings traded off against length are important because they affect engine nacelle weight, aerodynamic losses, and ultimately engine economics. The procedure is one which is based upon currently available theoretical and experimental information and thus has relevance at the present time but which must be updated and modified as new information and new situations arise. It is therefore not claimed to be a final procedure applicable for all time.

The design procedure described combines results from theoretical models of wave attenuation in acoustically treated passages with correlations of experimental data from full-scale fan suppressors. While theoretical models are satisfactory for laboratory duct experiments where the input wave structure is reasonably known and where simple geometries are employed, these models have not shown as good an agreement as desired in full-scale fan and engine experiments. For this reason experimental data from fan tests were correlated for setting peak attenuation levels and attenuation bandwidths. Parametric dependences derived from theoretical results were retained however.

The theoretical models that exist do not lend themselves directly to the design of a liner. The reason for this problem lies in the fact that the theory lends itself to evaluating the acoustic attenuation for a given installation. The general design problem, of course, asks for an installation specification to achieve a desired or target attenuation. To implement application of the theory to solve the design problem, the theoretical analysis was exercised parametrically to cover a wide range of installations. These parametric exercises combined with experimental data provide the basis for performance maps and equations which are used in the design effort.

The resulting procedure lends itself very nicely to screening a number of design configurations with respect to aerodynamic losses, installation weight, etc., and thus to the selection of the most pragmatic configuration. By introducing experimental data correlations from fan and engine tests, the treatment specification program accounts in an approximate way for "real-world" effects such as wall boundary layers, duct terminations, sound modal structure, and other similar effects to the extent that the influence of these effects can be generalized for a variety of fans and engines.

PROGRAM APPROACH

In the section PROCEDURE in this report, methods are presented for estimating source noise and for designing a liner to suppress the noise. Such an application is shown in figure 1. The source is considered to be a low tip speed fan with the fan jet as the noise floor. The suppressor design methodology employs rectangular duct theory and therefore applies specifically to annular passages such as the ringed inlet or the fan exhaust duct of figure 1. Some further work should enable the use of the procedure for designing cylindrical-duct suppressors. The suppressor design method could be applied to other noise sources having other noise floors. The various parts of the design problem fall naturally into a set of distinct, but interrelated, subpackages. As such, it is a straightforward matter to implement these subpackages in the form of subroutings to be called, as needed by a computer design program. Appendixes A and B contain listings of the required computer programs. As new information becomes available on the various components of the program, it is possible to incorporate changes into the proper subroutine or subroutines. It is also possible to perform the necessary steps of the design procedure by hand calculations, which are however tedious.

To design a noise suppressor to meet a required goal, it is necessary to have an estimate of the unsuppressed noise source spectrum. There are potentially several ways to secure such an estimate, for example through testing of the unsuppressed engine, or by theoretical prediction. The present procedure employs empirical noise correlations taken from the literature and modified somewhat as deemed necessary. It is not claimed that this is the best or the only way to achieve the required noise estimate; rather, it serves as one possible means of getting the needed information. As new and better information and/or prediction methods become available, they should be substituted for the present methodology.

A schematic representation of the interrelated parts of the present method is shown in figure 2. The design problem begins with an estimate of the noise produced by the fan, including the fan exhaust jet noise, which may constitute a floor for available noise reduction. This estimate is made using modifications of well-known noise correlations from the literature, which require specifications of certain design and operating parameters as inputs. From the calculated noise production and the desired noise goal (i.e., perceived noise level PNL), the required attenuation spectrum can be established. Combining the target attenuation spectrum with functional representations of liner behavior in an iterative fashion results in specification of the gross installation characteristics such as design frequencies of peak attenuation and required acoustic impedance. The number of rings, (e.g., as in fig. 1) and associated passage heights are chosen external to the computer program. Without the geometric constraints of the installation, the goal of these choices would be to obtain the most economically efficient attenuation of the noise.

The required acoustic impedance is used in an approximate mathematical impedance model that relates the required impedance to the detailed structure of the liner, including the cavity backing depth, face plate open area ratio, thickness, and perforation size.

This step, then, completes the design procedure as it presently exists.

Figure 2 also indicates the possibility for inclusion of a pressure loss estimate and installation weight estimate. Such capabilities would aid in the further optimization of liner design, but are not included in the present procedure.

If a measured fan noise spectrum is available, such a spectrum can be used at the appropriate step in the procedure, instead of calculating the fan noise estimate. A measured spectrum would be the best obtainable starting point for that specific application. Such a spectrum should be representative of the noise source in flight. An in-flight test is one way to measure the source noise. Alternately, if ground tests are used, care must be taken to avoid or correct for additional noise generation due to ground-static effects which would not be present in flight, such as ground vortices, flow distortions, inlet turbulence, and so forth. This point is discussed in further detail in reference 1.

In the course of the development of the liner design procedure, many simplifying assumptions were necessary. This need resulted in part from the very large matrix of possible applications and in part from the shortage of available information on certain aspects of the problem. For example, expressions for liner bandwidth cannot be obtained in general for all possible wall construction types because they depend on the particular impedance frequency characteristics involved.

Some of the major specializations and simplifications embodied herein are as follows:

(1) In the noise estimate procedure no multiple pure tones are considered.

(2) No noise floor other than the fan jet noise floor is considered.

(3) The acoustic absorber is assumed to be placed in an annular duct with flow Mach numbers equal to or less than 0.6. This restriction arises from the theoretical analysis of the duct sound propagation and from the empirical base for attenuation rates and wall impedances. It is reasonable to believe that extension to other cases could be accomplished if the effects were properly accounted for.

(4) The liner itself is of the perforated plate over honeycomb type. Generalization to other types of wall construction would require alterations of the bandwidth curves and adaptation of the impedance model used for specifying the wall construction. None of the simplifications contained here appear to invalidate the procedure. As additional information is made available, the procedure can be changed in a modular sense within the context of the present format.

With the foregoing discussion providing an overview, the detailed procedure will be discussed sequentially in the following sections.

ESTABLISHMENT OF TARGET ATTENUATION SPECTRUM

The noise generation calculation method, as discussed in this section, is presented as one means of providing the unsuppressed noise spectra needed for the design of a noise suppressor. These procedures are straightforward in their application. However, they may not be the best or most direct for all design problems. If the designer has information at his disposal which he considers more complete, or superior to that presented here, then of course he should use his own information as the preferred starting point. In particular, experimental measurement of the generated noise spectrum is a good way to secure an unsuppressed noise spectrum. Furthermore, if a designer has information about noise floors which might limit the noise reduction of a suppressor in addition to the fan jet floor discussed here, then that information should be taken into account for his purpose. An important point to consider is that the present design method provides a versatile framework within which such improvements can easily be made.

Figure 3 shows an example of a spectrum which has been calculated, for a low pressure ratio fan, using the noise correlations discussed in this section. The figure is presented here to provide a point of reference for discussion of the different parts of the noise estimate which follows. As seen in figure 3, the fan sound spectrum is broken into three parts: (1) internally generated tones, (2) internally generated fan broadband, and (3) externally generated fan jet noise. The manner in which the composite spectrum is assembled will be described in the discussion to follow.

Prediction of Internally Generated Noise

The internally generated noise of a low tip speed turbofan has generally been considered to be composed of discrete tones associated with the blade passing frequency of the fan and of broadband noise related to the turbulent flow of air over the internal surfaces of the machine. From a large number of tests of various engines, these noise components were correlated as functions of the fan operating parameters and geometry by Smith and House (ref. 2). Another, more recent, noise correlation procedure which could be used is given by Heidmann (ref. 3). The main motivation for selection of the Smith and House method was its availability at the time the present procedure was organized. Either method should provide reasonable noise estimates, and the computer could be provided with alternate subroutines to use either or both correlations.

The Smith and House correlation yields estimates of the noise spectra at the sideline angles of maximum noise in both the inlet and exhaust hemispheres. The correlation is expressed simply in terms of normally available fan parameters. Comparison of the results of the Smith and House correlation with experimental results of reference 4 and with more recent, as yet unpublished, turbofan results has indicated the need to modify the Smith and House correlation in order to give reasonably accurate correlations of the noted recent results. The Smith and House correlation was developed from machines having inlet guide vanes, while the present applications have none. It is assumed that the present rotor-stator interaction noise behaves in the same way as the inlet guide vane-rotor noise correlated by Smith and House.

Broadband noise. - For fans with no inlet guide vanes, the correlation for predicting the sound pressure level at the peak of the broadband noise curve SPL_{pBB} is

$$SPL_{pBB} = 75. + 10. \log \mathscr{M} + 50. \log\left(\frac{V_{tip}}{1000}\right) + \Delta F \tag{1}$$

where $\mathscr{M}$ is the air flow rate through the fan in pounds per second, V_{tip} is the tip rotative speed of the rotor in feet per second, ΔF is an adjustment for the front-rear directivity split of sound from the fan and is a function of the tip relative inlet Mach number of the fan. Then,

$$\Delta F = 10. \log (1 + M_{tip}), \qquad M_{tip} \leq 0.8 \tag{2}$$

In the original method positive and negative values of M_{tip} were used for rear and front maximum angles, respectively. However, it was found for the experimental results in the Quiet Fan Program that the prediction works well at the front angles but not at rear angles where the broadband is about the same as in the front. Therefore ΔF was calculated using positive M_{tip} for both front and rear estimates. Thus the change of sign in the original method is ignored for the broadband noise. Note that the calculation gives the peak sound pressure level at the front maximum (50^{o}) and rear maximum (120^{o}) noise angles, on a 30.5-meter (100-ft) sideline. The frequency of the broadband noise peak in Hertz as given by Smith and House is

$$f_{pBB} = \frac{10\ 000}{Ch} \tag{3}$$

where Ch is taken, for fans without IGV's, to be the average of the axial chords at the tips of the rotor and stator given in inches.

The shape of the broaeband spectrum is estimated by a log normal curve fit of the spectral data of $SPL - SPL_{pBB}$ presented by Smith and House (ref. 1) to be

$$SPL_{BB} = SPL_{pBB} - 50. \left(1 - e^{-X^2}\right) \tag{4}$$

where

$$X = \log\left(\frac{\frac{f}{f_{pBB}}}{0.883}\right)10.995 \tag{5}$$

The constant 0.883 causes a minor adjustment of the actual peak of the bell-shaped curve fit of equation (4) from that calculated by equation (3). This shift is not a significant effect, but is required to cause the bell to fit the Smith and House results in a best sense. The resultant broadband spectrum is shown in figure 4.

Discrete tone noise. - The discrete tones are predicted using the following equation:

$$SPL_{tn} = 85. + 10.\ \log \mathscr{M} + 50.\ \log\left(\frac{V_{tip}}{1000}\right) - 20.\ \log\left(\frac{S}{Ch}\right) + \Delta F - 20.\ \log n \tag{6}$$

where $\mathscr{M}$ is the air flow rate in pounds per second; S/Ch is the ratio of axial rotor-stator spacing to mean of the axial projection of the tip chord of the rotor and stator, and n indicates the n^{th} harmonic of the blade passing tone. In the case of the tones, ΔF is used as intended by Smith and House in the front and in the rear; that is, both negative and positive signs are used on M_{tip} as appropriate.

The frequencies at which the tones occur are found as follows:

$$f_{tn} = \frac{RPM}{60}\ Bn \tag{7}$$

where RPM is the fan speed in revolutions per minute, B is the number of rotor blades, and n is the n^{th} harmonic of the blade passing tone (n = 1 for the fundamental). Each tone is placed in the one-third octave band containing the frequency of the tone. If two or more harmonics fall within a particular band, the intensities are added and the resultant sum is used. No attempt is made to divide the power between two adjacent one-third octave bands when a tone falls near the theoretical boundary between two bands.

Combined spectra. - Combining the broadband and tone noise leads to the estimated spectrum of internally generated noise available for suppression. Recall that no predictions of multiple pure tone noise are included in the method; therefore, such cases are excluded from consideration. As discussed previously, figure 3 shows an example spectrum of this internally generated fan noise combined with the estimated fan exhaust jet noise. The fan parameters for the NASA Lewis QF-9 fan (low tip speed and pressure ratio, ref. 5) were used for the example calculation, and their values are given in table I. To assemble the spectrum, the fan broadband noise is used as the starting spectrum. At those one-third octave bands where the estimated tone level exceeds the broadband, the tone level replaces the broadband point. If the tone level is equal to or

TABLE I. - FAN DESIGN PARAMETERS FOR CALCULATION

OF SOURCE NOISE ESTIMATE OF QF-9 FAN

Fan speed, RPM	2227
Number of rotor blades, B	15
Fan weight flow, $\mathcal{M}$, kg/sec (lb/sec)	404 (890)
Spacing to chord ratio, S/C	2
Tip Mach number, M_{tip}	0.63
Mean axial chord, Ch, m (in.)	0.316 (12.45)
Jet exit area, A, m^2 (ft^2)	2.02 (21.76)
Jet characteristic length (passage height, L_c, m(in.)	0.473 (18.6)
Jet velocity, v_j, m/sec (ft/sec)	177 (579)

below the broadband, the one-third octave band point remains unchanged.

There have been some unsatisfactory results with attempts to compare this tone noise prediction to measured data for a wide range of fans. Poor comparisons are attributed in part to the rotor-stator spacing term in the prediction, which may not be applicable to fan noise data in static tests. This observation is made because of the recently advanced postulate that inlet distortion and inlet turbulence interacting with the rotor are major sources of tone noise in static testing of fan stages (refs. 1, 6, 7, 8, 9, and 10). If such were the case, it is clear that rotor wake-stator interaction would not necessarily be the dominant source of tone noise and that therefore attempts to account for the rotor-stator spacing effect could introduce scatter into the comparison between predicted and measured tone noise. It is probable that, for fans in which rotor wake-stator interaction is the dominant source of tone noise, the rotor-stator spacing dependence used here is a good approximation. This may apply to the higher harmonics of the fan tone statically and to the fundamental tone in flight, provided it is above cutoff. For purposes of estimating the spectra of preliminary fan designs for use in examing liner tradeoffs, the relations presented are very useful.

Prediction of Fan Jet Noise

The externally generated fan exhaust jet noise is important because it represents an ultimate noise floor below which the addition of more acoustic treatment would yield no observable reduction of the far field fan noise and because it contributes to the perceived noise level. Thus the fan jet noise presents a practical and ultimate limit for noise attenuation by acoustic liners, unless the observer might be shielded from the jet noise, such as in an engine-over-the-wing configuration. In addition to the fan jet noise, there are other sources in a complete turbofan engine which need to be considered as potential floors for such a machine. For example the core engine jet noise, the combustor noise and the core engine turbine noise may be significant sources which should be considered when warranted. Other noise floors, such as self-generated noise by the flow over the treatment, may lie above the fan jet noise and thus become the real limit in some cases. However, little is known about treatment of self noise.

In the interest of simplicity, the present development is limited to the specific application of a turbofan with its associated single stream exhaust jet noise as the noise floor. Extension of the present design method to cover other situations would not require significant effort, given the needed information about other noise sources.

The jet noise is estimated using a procedure based on the "SAE correlation" (ref. 11) which has been modified to account for the results reported in reference 12. A recently published jet noise prediction method is that of reference 13, which could be used as an alternate to that used in this report. The present methodology uses the former, since the development of the present procedures preceded the publication of reference 13. The level of the jet noise is set by considering the maximum jet noise overall sound pressure level $OASPL_m$ at an angle of maximum jet noise on a 30.5-meter (100-ft) sideline as a function of jet size and velocity. Figure 5 shows a plot of $OASPL_m - 10 \log A$ as a function of jet velocity. This curve was taken from reference 11 and adjusted in level in order to remove jet density from the correlation parameter such that the curve passes through the fan data of reference 12. For use in the computer, the curve shown in figure 5 is represented as

$$OASPL_m = 93. \log v_j + 10. \log A - 176.2 \tag{8}$$

The result of this equation, using v_j in feet per second and A in square feet, is the jet $OASPL_m$ at a 30.5-meter (100-ft) sideline and maximum angle. The jet noise maximum angle in a sideline representation is assumed to occur at 135^o from the engine inlet centerline.

In order to estimate the level of the jet noise at the same far field point as the internal noise levels (namely 50^o and 120^o on a 30.5-meter sideline), adjustments are made for the distance and directivity effects. The directivity information is taken from reference 12 and is shown in figure 6 as the variation of OASPL directivity index as a function of angle. The value of the OASPL at an angle other than the maximum sideline jet noise angle can be calculated using the directivity index. The curve of figure 6 is used to find the difference between the directivity indices at the desired angle and the angle of maximum OASPL. This difference, when added to the $OASPL_m$, yields the value of OASPL at the new angle on an arc passing through the maximum jet noise location (135^o, 30.5-meter sideline). The jet noise estimate is then adjusted to the 50^o and 120^o, 30.5-meter sideline positions of maximum internal noise by making a distance correction, assuming a point source and including a small adjustment for atmospheric absorption.

The directivity index curve was drawn through the data of reference 12. A table of values was taken from this curve and stored in the computer for adjustments to the desired locations. Since the OASPL directivity and a fixed-shape jet noise spectrum are used, it follows that no account is taken of possible variations in directivity of different frequency bands.

The Strouhal spectrum of fan jet noise was taken from reference 11 and was fitted with a segmented analytical expression for ease in computation. The curve is shown in figure 7. To find the jet noise spectrum for a specific fan, the following procedure was used. A dimensionless Strouhal number fL_c/v_j was used to normalize the spectrum where f is frequency, L_c is the characteristic length, and v_j is jet velocity. For the present, L_c was set equal to nozzle annulus height, which was found to work well for the spectra of reference 12. To predict one-third octave spectra, a simple level adjustment from the octave-band spectrum is made.

It is observed that the jet noise correlation, thus modified, may provide a reasonable estimate for the fan jet noise from turbofans which are similar in geometry to that of reference 12, that is, small annulus height as compared to the diameter and long trailing center body. For significantly different fans the results may be in error. This comment applies mainly to the use of annulus height in the Strouhal number for placement of the spectrum, with respect to frequency.

The total noise picture is formed by energy adding the jet noise spectrum to the internally-generated spectrum as shown in figure 3.

Comparison with Measured Noise Data

Figure 8 shows a sample comparison at 120° between the data measured on the QF-9 fan of reference 5 and the noise estimation results discussed previously. Agreement is seen to be quite good. The agreement is seen to be poorest at frequencies below 250 hertz. The discrepancy there is probably due mainly to the fact that there is a ground interference problem in the data which is not included in the estimate. The apparent over-prediction of the blade passing frequency tone (first spike) is due in part to the splitting of the measured tone between the 500- and 630-hertz bands. As noted earlier such splitting does not occur in the estimate. As a rough comparison, all of the measured tone can be placed in the 500-hertz band by adding about 2.5 decibels there. The resulting comparison is reasonably good. It should be noted that the QF-9 results were not used in the data base which determined the estimation procedure.

In contrast with the good agreement shown here, there have been other cases where the agreement was not so good. This result is attributed to the general simplicity of the correlation procedure in representing a complicated process. It is, however, argued that, as long as the fan for which a noise prediction is sought is reasonably similar to those which formed the empirical basis for the estimation procedure, the resulting noise estimate should be reasonably good for the purposes of the method.

Note that no attempt is made to give a noise estimation procedure for fans having buzz-saw or multiple pure tone noise. This additional source should be considered when appropriate. At present no general multiple pure tone prediction method exists; however, an interim method published in reference 3 can be used to calculate an estimate pure tone noise for high (supersonic) tip speed fans.

Target Attenuation Spectrum

The object of placing an acoustic liner in a fan duct is to reduce the annoyance (perceived noise) of the noise to an acceptable level. To ascertain the amount of reduction required, the designer needs to have a quantitative measure of the annoyance caused by a sound pressure level spectrum such as that of figure 3. Reference 14 presents a method relating a quantity called Noys, which is directly proportional to human annoyance, to sound pressure level as a function of one-third octave frequency band. The effect of this quantity is to provide a weighting function which accounts for the fact that some sound frequencies produce greater annoyance than others. Figure 9 shows the spectrum of annoyance (Noys) derived from the estimated sound pressure level spectrum of figure 3, using the method of reference 14. It is notable that the frequency range from 1000 to 4000 hertz is heavily weighted, and the tone at 500 hertz contributes a substantial amount of annoyance.

Once the target perceived noise level PNL is known, it is possible to find a sound pressure level spectrum which meets the goal. A simple first choice for a spectrum having the target PNL value is that for which the sound in each one-third octave band is equally annoying. Figure 9 includes a flat Noy "spectrum" which would lead to 90 PNdB. This value of Noy was derived using the method of reference 14. The equation for perceived noise level is

$$\mathrm{PNL} = 40 + 33.21 \log \eta \tag{9}$$

where

$$\eta = 0.85\ \mathrm{Noy}_{max} + 0.15 \sum_{\text{all } 1/3 \text{ oct}} \mathrm{Noy}_i \tag{10}$$

For the case where Noy_i is a constant Noy_c, this equation becomes

$$\eta = (0.85 + 0.15\ N_f)\ \mathrm{Noy}_c \tag{11}$$

where N_f is the number of frequency bands and Noy_c is the constant value of Noy. Rearranging equations (9), (10), and (11) reveals that

$$Noy_c = \frac{\eta}{0.85 + 0.15\ N_f} \tag{12}$$

and

$$\eta = 10.^{(PNL-40.)/33.21} \tag{13}$$

Solving for Noy_c gives

$$Noy_c = \frac{10.^{(PNL-40.)/33.21}}{0.85 + 0.15\ Nf} \tag{14}$$

Finally, with this value of Noy, it is possible to enter a table or an equation which relates SPL, Noy, and frequency to yield a sound pressure level spectrum with the target PNL. A subroutine which employs a curve fit of the relation from reference 14 is used for the calculation of the spectrum. Figure 10 presents a sound pressure level spectrum calculated by this subroutine yielding a constant 7.2 Noy level and having a resulting value of 90 PNdB.

It should be obvious at this point that there are an infinite number of possible sound pressure level spectra which would result in a given goal PNL. The flat Noy spectrum is a simple choice for this purpose. The individual designer could, of course, make some other choice which could be implemented in a fairly simple way.

A perceived noise level goal is generally specified at a distance greater than the 30.5-meter (100-ft) sideline discussed in the preceding noise estimation procedure. Therefore before the difference between the goal spectrum and the noise-generation spectrum can be calculated, the generated spectrum must be adjusted to the desired distance. In the present case, the generated spectrum is adjusted to the distance of the goal, accounting for noise reduction due to distance and excess atmospheric attenuation.

Once the target spectrum has been determined, it is an easy matter to subtract the target spectrum from the predicted noise generation spectrum to obtain the resultant target attenuation spectrum for the liner, keeping in mind that the noise cannot be reduced by the liner below the level of the fan jet noise. Figure 11 presents an example of a target attenuation spectrum at 120°, using the noise generation estimate shown in figure 3 for the 1.2 pressure ratio (QF-9) fan at design condition and the target flat Noy spectrum of figure 10 calculated to reach the 90 PNdB goal.

In order to establish a target attenuation spectrum, it was necessary to examine the spectrum of sound pressure level at the angle of maximum annoyance and to compare this spectrum with a predetermined desired attenuated spectrum. In the previous illustrative example, this angle of maximum annoyance was 120°. Recall also that the forward angle of maximum annoyance using the noise estimation procedure of this report occurs at 50°. For the situation where the designer has other information at his disposal on maximum annoyance spectra, he should, of course, use that information.

The determination of noise estimates at the forward maximum and rear maximum angles, along with noise goals, as discussed previously, allows the calculation of sound attenuation requirements for inlet and exhaust suppressors, respectively. The target sound pressure level attenuation spectra are assumed to convert directly to target power level attenuation spectra for the suppressors. This assumption implies that the inlet suppressor attenuates uniformly over the inlet hemisphere and that the exhaust suppressor attenuates uniformly over the exhaust hemisphere. Furthermore, it is implied that there is no significant noise effect in the inlet hemisphere from exhaust noise, and vice versa. These assumptions are necessary in the absence of sufficient information on attenuation directivity effects. It is known, however, that this procedure should yield attenuation estimates for the liner which are conservative at the angle of maximum noise.

Appendix A contains a listing and a discussion of a FORTRAN IV computer program to perform the calculations indicated for determination of target attenuation spectra. The example problem carried through this report is also included as input-output listings.

SPECIFICATION OF LINER DESIGN

The procedures which are set forth herein apply specifically to the design of an acoustic liner for an annular passage having opposing walls treated with identical materials. The liner itself, seen schematically in the insert in figure 1, has a perforated face sheet backed by honeycomb with an impervious wall behind the honeycomb. Any deviations from this type of liner would have to be taken into account by altering some details of the design procedure presented here.

In effect, the present procedure considers the design of a single annular acoustical passage, and it must be assumed that any parallel passages (for example when splitters are present, as seen in the inlet of a research fan, fig. 1) will be constructed to accomplish the same attenuations. Alternatively the passage considered most important for design might be the outermost passage. The profile of sound intensity, as well as area distribution, often is high at the outer wall and falls off toward the center, thus concentrating a large portion of the sound energy in the outer passage. Nevertheless, the inner passages cannot be ignored in the overall suppressor design, because they will allow a noise leak if they are poorly designed. Furthermore, the passage heights and number of splitters must be compatible with the overall geometry of the installation. The number of splitters and related passage heights are not presently handled automatically by the program, but are set externally in an iterative manner in such a way as to accomplish the desired attenuation within the physical constraints of the duct, while allowing for splitter thickness.

The liner design proceeds in essentially two phases. The first phase employs the combined experimental results and theoretical propagation analysis in order to specify the required acoustic design; that is liner peak attenuation frequency, liner length, and optimum liner impedance. In the second phase of the design, the tuning and optimum impedance requirements of the first phase are translated into hardware designs using an empirical mathematical model for wall impedance to specify perforated sheet open area ratio and honeycomb backing depth. Such items as facing sheet thickness, hole diameter, and honeycomb cell size are selected as inputs to the program based on availability of materials, ease of fabrication, cost, or other pragmatic considerations. These parameters do have an influence on acoustic performance and cannot be changed arbitrarily once the remainder of the installation has been specified based on some choice of these parameters.

Phase 1 - Acoustic Design

The parameters to be specified in this part of the design procedure are passage heights, tuning frequencies, length of treated surface and optimum impedance at the frequency of peak attenuation. A number of reports in the literature, such as reference 15, 16, and 17, have presented results of analytical calculations of liner attenuations. Some typical kinds of problems considered have been propagation of plane wave, or spinning modes, or least attenuated modes. For purposes of the present design procedure in order to limit the complexity of parametric relations, the curves of attenuation for least attenuated mode in a rectangular duct were selected as presented in reference 17. The rectangular duct is a good approximation to the annular passages in an inlet with splitter rings and in the fan exhaust. The items to be considered in this section involve the prediction of the liner performance in terms of the variables discussed in the preceding paragraph. The basis for these predictions are theoretical analyses of acoustic propagation for both optimum and off-optimum impedances. To improve agreement with experimental observations, an empirical constant has been introduced to adjust the levels of the estimates. Establishing the spectral estimates by this means as functions of the noted parameters enables the design choice of the parameters to achieve a target attenuation.

Peak attenuation at optimum impedance. - One of the results of the propagation analysis is the prediction of sound attenuation at the frequency of peak suppression at optimum impedance, for the rectangular duct least-attenuated mode. This peak suppression was predicted as a function of duct Mach number M, duct length L, duct height H, peak frequency f_p, and speed of sound c. For the least attenuated mode these parameters were combined; and the prediction was presented concisely in terms of dimensionless parameters as shown in figure 12.

Experimental data at the Lewis Research Center have shown that the attenuation attained in practice for ringed liners is less than that predicted by the theoretical curves of reference 17. Therefore the curves presented here in figure 12 have been adjusted to show suppression levels only 0.4 times those in reference 17.

It is normal practice to summon a large collection of data in order to specify an empirical factor. In the present case experimental results from tests on a single inlet liner were used to arrive at the factor of 0.4. This was done because of the extreme difficulty of attempting to correlate measured attenuations from suppressors which were off optimum by varying amounts. It is, however, a relatively easy exercise to employ the prediction procedure, once the empirical factor has been determined, to calculate estimates for other suppressors and thereby verify the empiricism against other data. Limited comparisons of this nature are presented later in this report. The agreement has been good for cases examined to date. However, such comparisons should continue in order to further build confidence in the empiricism.

The details of the technique used to specify the 0.4 constant factor were as follows. Spectral attenuation data from reference 18 for the inlet suppressor in the QF-1A fan testing program were used. The details of the acoustic design for this liner are given in table II.

TABLE II. - QF-1A LINER USED FOR EMPIRICAL ADJUSTMENT OF PEAK ATTENUATION CURVES

[Duct Mach number, M, -0.32; duct temperature, T, 288 K (519° R); static pressure, p, 9.32×10^4 N/m^2 (13.5 lb/in.^{2}); duct height, H, 20 cm (7.9 in.); sheet thickness, t, 0.051 cm (0.020 in.); hole diameter, d, 0.081 cm (0.032 in.).]

Open area ratio, σ, percent	Back cavity depth, b		Equivalent length, L		Calculated peak frequency f_p, Hz	Calculated resistance ratio, θ/θ_{opt}
	cm	in.	cm	in.		
2.5	0.51	0.20	38	15.	2741	1.4
2.5	2.23	.88	48	19.	1184	4.6

The attenuation spectrum, rather than the attenuation at a single frequency, was used in order to increase the data base for the factor. Making the calculated estimate for this spectrum, required considerations of off-optimum impedance and liner bandwidth behavior which to this point have not been discussed here. The use of these details was consistent with the discussions to follow.

Figure 13 presents the comparison between the QF-1A data and the adjusted predicted estimate. Note that the fit is quite good. Included among the experimental results are attenuation spectra from several different speeds. These data with the exception of the tones, exhibit a good correlation about a single faired curve.

The reason for the large shift between the pure theoretical prediction and the experimental results (as reflected in the factor 0.4) is not fully understood. A possible cause may lie in boundary layer and mode shape effects, which are not explicitly included in the present method and which could therefore tend to de-optimize the impedance, thus reducing attenuations below those expected.

As seen in figure 13, there are several data points (tailed) which lie above the general trend. These points represent attenuation of tones which may damp rapidly because they occur as spinning modes, as discussed in reference 16 or as higher order radial modes. The present procedure does not consider spinning modes or higher order radial modes, and therefore these data points were not included in setting the value of the empirical constant. If tones damp faster than broadband sound as these data suggest, a parallel method for predicting the attenuation of tones is needed. However, the present procedure when applied to tones would provide conservative estimates of attenuation.

For use in the computer, the curves of figure 12 were expressed in the form of equations. The entire curve for zero Mach number was fitted with a single equation for which the form was motivated by the shape of the curve as follows:

$$\left.\frac{(\Delta PWL_p)_{opt}}{\frac{L}{H}}\right|_{M=0} = 0.4\left\{\left(\frac{B_5}{B_4+\eta}\right)e^{B_1 e^{-(1/2)\left[(\ln\eta - \ln B_2)/B_3\right]^2}}\right\} \tag{15}$$

where B's are curve-fit constants, given in table III(a), and η is the dimensionless frequency parameter $\eta = Hf_p/c$.

The curves at $M \neq 0$ are fit by considering the deviation from the $M = 0$ curve, such that

$$\left.\frac{(\Delta PWL_p)_{opt}}{\frac{L}{H}}\right|_{M} = \left.\frac{(\Delta PWL_p)_{opt}}{\frac{L}{H}}\right|_{M=0} + 0.4\,Del_k \tag{16}$$

where

$$\mathrm{Del}_k = D_{k1} \frac{D_{k2}}{D_{k4} + \eta} - D_{k3} \tag{17}$$

The k subscript indicates that the curve-fit constant D's are different at different Mach numbers. The values of D_{kl} are listed in table III(b) for the Mach numbers shown in figure 12. For other Mach numbers the peak attenuation is found by interpolating. This is done in the computer by using a pair of interdependent interpolation routines, taken from references 19 and 20. At values of Mach number outside the range shown in table III, the use of extrapolation may not be reliable.

TABLE III. - CONSTANTS FOR CURVE FIT OF

LINER PEAK ATTENUATION (EQ. 15)

(a) No flow case (duct Mach number = 0)

$B_1 = 0.41792$
$B_2 = 0.57188$
$B_3 = 0.64086$
$B_4 = 0.23905$
$B_5 = 14.167$

(b) Duct flow case (Mach number general), eq. (17)

Mach number, M	Integer k	Integer l			
		1	2	3	4
		Values of D_{kl}			
-0.4	1	1.5475	45.497	18.811	2.4012
- .2	2	1.1661	10.937	9.3986	1.1438
0.	3	0.	0.	0.	0.
.25	4	-2.0987	30.741	12.255	2.4699
.4	5	-3.5123	49.095	13.861	3.5251
.5	6	-4.1881	48.918	14.121	3.4267

There are instances when it may be advantageous to design a liner with an impedance which is off-optimum at the frequency of peak attenuation. Such a design could have the advantage of a broader bandwidth than an optimized liner. However, when the liner resistance is not optimized, the magnitude of peak attenuation is adversely affected.

Performance at off-optimum impedance. - This section presents background information which led to the design procedure presented in other sections. The reading of this section is not necessary to the application of the method. In order to estimate an attenuation spectrum for the liner to be designed, it is necessary to know how the liner behaves at frequencies away from the frequency of peak attenuation. Therefore the bandwidth characteristics of the liner must be determined. The peak sound power attenuations shown in figure 12 and the liner optimum impedance study reported in reference 16 provide information at only one frequency, the peak attenuation frequency, and this only if the liner is optimized. For the rest of the attenuation spectrum, off-optimum performance must be considered.

Determination of the attenuation spectrum is made by combining results from the theoretical propagation analysis with calculations of impedance from a semi-empirical impedance model for a specific kind of wall material. The propagation analysis results in sets of contours of constant attenuation on an impedance plane plot. These contours are generated under some idealized assumptions. It is assumed that, at any given frequency, the impedance, specific resistance θ, and specific reactance χ (which are parameters normalized by ρc, the free space impedance) can be varied arbitrarily. Thereby a relation between resistance and reactance, which leads to constant values of attenuation, can be found. Changing the frequency results in a new set of contours. The impedance of an actual liner has a specific dependence on frequency, on liner geometry, and on environmental conditions. This dependence is approximated by the impedance model. The combination of the propagation analysis and the impedance model to give an attenuation spectrum is a somewhat complex process which is described in greater detail in reference 21. A brief illustration of the basic ideas involved will be presented here.

In reference 21 it was found that the constant attenuation contours could be approximated by a series of circles in the impedance plane described previously. This series of circles was represented by a single equation containing only the maximum possible sound power attenuation and optimum wall impedance as inputs. Figure 14 shows an illustrative example using conceptual contours at three different frequencies: f_i, 0.5, and 2 f_i (solid, dashed, and dash-dot curves, respectively). On any one of the contours the attenuation is a constant for that frequency. The attenuation shown on the curves are all relative to the peak attenuation, which is taken as unity, at f_i. The peak attenuations at 0.5 f_i and 2 f_i were set relative to that at f_i by using the inverse liner dependence of attenuation on the frequency parameter as shown in figure 12 for values of $\eta > 2$. At one-half the intermediate frequency, the peak attenuation is two; while at twice the intermediate frequency, the peak attenuation is one-half. The optimum resistance θ_{opt} and reactance χ_{opt} vary as

$$\left.\begin{matrix}\theta_{opt}\\ \chi_{opt}\end{matrix}\right\} \propto f \tag{18}$$

which is valid for $M = 0$. If $M \neq 0$, for equation (18) to be valid, the mode must be well cut-on (propagating), as was shown in reference 16.

As noted previously, the complex value of impedance was allowed to vary arbitrarily in order to construct the contours of figure 14. The impedance of an actual liner does not vary in an arbitrary way. In order to use the contours of figure 14 to calculate attenuations, it is necessary to introduce the actual behavior as a function of frequency. To demonstrate the technique, two separate illustrative examples will be considered.

In the following discussion of impedance, it is convenient to consider the resistance and reactive components individually. The actual resistance will be assumed independent of frequency; this is a reasonable assumption, in particular whenever there is significant flow past the liner surface. The actual wall specific reactance is modeled by the following cotangent relation:

$$\chi = -\cot \frac{\omega b}{c} = - \cot \frac{2\pi f b}{c} \tag{19}$$

where ω is radian frequency, b is cavity backing depth, f is frequency (Hz), and c is the speed of sound. For the present illustrative examples, equation (19) will be approximated by

$$\chi \propto - \frac{1}{f} \tag{20}$$

The first example is a liner with its values of resistance and reactance at frequency f_i coinciding with the optimum values for that frequency. This point is shown as an open diamond in figure 14. At other frequencies the liner resistance is a constant, as assumed previously, and the reactance is described by equation (20). Therefore the liner impedance value lies on a horizontal line passing through the optimum point. Two other points on this line are called out: the open square at a frequency of $0.5\ f_i$ and the open triangle at a frequency of $2\ f_i$. When $\theta = 1$ and $\chi = -1$ the wall impedance coincides with optimum impedance for f_i, and the relative attenuation is one. For $0.5\ f_i$ the actual wall specific resistance is $\theta = 1$, and the specific reactance is $\chi = -2$, and this point must be associated with the dashed contours. The relative attenuation is thus seen to be 0.53. For $2\ f_i$ the actual wall specific resistance is $\theta = 1$, and the specific reactance is $\chi = -0.5$, which is associated with the dash-dot contours. The relative attenuation is seen to be slightly less than 0.2, say 0.19. Therefore the fall off in attenuation with frequency is seen to be faster on the high frequency side than on the low frequency side of the optimum. This is seen to be due to the displacement of the actual wall impedance and of the optimum loci with frequency, as well as to the reduction of the maximum possible attenuation with increasing frequency.

The second example is a liner with a value of resistance which is too large to give maximum possible attenuation at any frequency, as shown in figure 14 as solid symbols. The liner characteristics are chosen such that at frequency f_i, the actual liner reactance equals the optimum value of reactance for that frequency (diamond-shaped symbol). At other frequencies the liner resistance and reactance are specified as before. The values at 0.5 f_i and 2 f_i are illustrated by the square and triangles, respectively. For the overdamped (large resistance θ) off-optimum liner the peak attenuation is seen to be around 0.56 (solid curves). The one-half and double frequency points are seen to have relative attenuations of about 0.51 and 0.34, respectively. Although the peak attenuation is down to one-half the optimum peak, the attenuation spectrum is seen to be relatively flat, which is typical of overdamped systems. The two examples discussed here have shown in principle the way that attenuation is calculated for a liner with known or assumed impedance behavior. By considerations of this nature the complete liner behavior as a function of frequency (referred to as bandwidth) can be calculated for a liner with optimum or off-optimum values of impedance. The general relations to follow depend on the precise nature of the actual liner impedance, and any changes from the assumptions used here would necessarily alter the general relations.

Off-optimum peak attenuation. - For a liner which is not optimized, the frequency of peak attenuation occurs at the frequency where the reactance equals the optimum reactance. The peak value of attenuation in the spectrum is reduced in amplitude from that possible with an optimized liner because the resistance does not equal the required optimum resistance at this frequency.

The complete determination of liner off-optimum performance required considering a large number of cases similar to those in the preceding section; however, the more precise formulation of equation (19) was used instead of the approximation of equation (20) to develop the relations to follow. This section presents the results for off-optimum peak attenuation, and the next section presents the results for bandwidth, which also arises from off-optimum impedance values.

The calculated ratio of peak attenuation to maximum possible attenuation is shown in figure 15 as a function of liner resistance ratio. This quantity is also a function of the frequency parameter η (for overdamped liners); thus there is a separate curve for every value of η. As expected, the maximum peak attenuation is obtained when the liner is optimized ($\theta/\theta_{opt} = 1$), and either overdamping ($\theta/\theta_{opt} > 1$) or underdamping ($\theta/\theta_{opt} < 1$) reduces the peak attenuation. As will be seen in the following sections, one might design an overdamped system to increase the attenuation bandwidth at the expense of the peak attenuation.

Liner bandwidth. - The previous illustrative example, in connection with figure 14, demonstrated the principle of the method used to calculate the spectrum of attenuation for a liner. The procedure discussed could be used for every value of frequency of interest. This procedure has been simplified such that the attenuation spectrum is assumed to be characterized by the sketch in figure 16. Once the peak attenuation is established, the only remaining information necessary for an estimate of the attenuation spectrum are the half attenuation frequencies above and below the peak. The frequencies f_1 and f_2 are the frequencies at which one-half of the peak attenuation is obtained. This representation of the attenuation spectrum should be adequate for preliminary design calculations.

In figure 17 the bandwidth frequencies f_1 and f_2 are shown as functions of design parameter η for a liner with an optimized resistance. The values of f_1 and f_2 have been calculated from a combination of the equal attenuation contours and the liner actual impedance behavior. The bandwidth is seen to be extremely small for low η with some broadening at high η. This is due to the stretching of the equal attenuation contours of figure 14 at higher values of the frequency parameter (resistance also higher). It should be recalled from the illustrative example that, as the bandwidth increases, the peak attenuation decreases with increasing frequency parameter (see fig. 12). Therefore a careful examination of both phenomena must be made in order to design a liner.

The low-frequency half attenuation point f_1/f_p for off-optimum liners is shown in figure 18(a) for several values of design frequency parameter. For underdamped liners $(\theta/\theta_{opt} < 1)$, f_1/f_p is essentially constant. Thus very little gain in bandwidth occurs; but peak attenuation is lost, as can be seen in figure 15. For an overdamped liner $(\theta/\theta_{opt} > 1)$ considerable bandwidth increases are obtained with increasing resistance.

The high-frequency half attenuation point f_2/f_p for off-optimum liners is shown in figure 18(b) with η as a parameter. Note that, as with f_1/f_p, f_2/f_p remains constant for $\theta/\theta_{opt} < 1$; and as θ/θ_{opt} increases above one, the bandwidth increases. The curves of figure 18(b) at values of $\eta < 10$ are adjusted from those one would derive directly from use of the cotangent relation of equation (19). In brief the adjustment was required to eliminate unrealistic behavior of the cotangent function at certain values of its argument, namely 0, π, and so forth. This point is discussed in greater detail in reference 21.

For purposes of the present design procedure, the curves of figures 15 to 18 are used to calculate bandwidth and off-optimum liner performance estimates. The curves in these figures were fit by a series of straight line segments on the log-log basis for ease of implementation in the computer. For values of η which fall between these curves, interpolation subroutines from references 19 and 20 were used to calculate the needed values.

Application to Liner Design

Procedure. - Once the peak attenuation and the bandwidth have been specified as indicated, the matter of designing the liner is accomplished by choosing design variables so that the goal attenuation spectrum is fit in a least-squares sense. This procedure can be summarized functionally as follows: The total estimated liner attenuation spectrum is the sum of the spectra from the N liner segments given by

$$\Delta dB(f_c) = \sum_{j=1} \Delta dB_j(f_{pj}, L_j, H, f_c) \tag{21}$$

where f_c is one-third octave center frequency, j is an index for a particular liner segment, f_{pj} is the peak frequency for that liner segment, L_j is the length, and H is the duct height. The sum of the squares of the deviations between the estimated liner attenuation and the target attenuation spectrum over the one-third octave center frequencies of interest is

$$Y = \sum_{\text{all } f_c} \left[\Delta dB(f_c) - \Delta dB_t(f_c)\right]^2 \tag{22}$$

The extent of the one-third octave spectrum used in equation (22) is somewhat arbitrary. Selection of this range must be based on the shape of the target spectrum.

The least-squares calculation makes the selection of f_p's and L's in such a way as to minimize Y. The number of peak frequencies N and the duct height H are set by practical considerations of the geometry. The minimization of Y is done by selecting each variable so that each of the derivatives

$$u = \frac{\partial Y}{\partial w} \rightarrow 0 \tag{23}$$

where w represents each one of the variables f_{pj} and L_j. Thus the deviation is minimized with respect to each variable. The derivatives are evaluated by a numerical procedure in which each of the design parameters is guessed and then incrementally stepped. New values w_{new} of the parameters are chosen by Newton-Raphson iteration in which

$$w_{new} = w_{old} - \left.\frac{u}{\left(\frac{\partial u}{\partial w}\right)}\right|_{w_{old}} \tag{24}$$

The iteration stops when w_{new} is within an acceptable tolerance of w_{old} for each of the variables sought.

Example results. - Using the techniques discussed previously, an example liner was designed for the target attenuation spectrum of figure 11 for the QF-9 fan aft duct. The resulting liner specifications are shown in table IV together with some input environmental parameters listed in the headnote. These parameters were assumed rather than actual for this machine. This example is also included in appendix B to demonstrate the application of the liner design program.

TABLE IV. - SAMPLE ACOUSTIC LINER DESIGN PARAMETERS FOR QF-9

EXHAUST DUCT SUPPRESSOR

[Duct Mach number, M, 0.4; duct temperature, T, 288 K (519° R); static pressure, p, 1.034×10^{5} N/m^2 (15 psia); duct height, H, 0.246 m (9.70 in.).]

Section	Peak frequency, f_p, Hz	Dimensionless frequency, η	Length to height ratio, L/H	Specific resistance, [a] θ	Specific reactance, [a] χ
1	502.	0.36	2.41	[b]0.595	0.191
2	3011.	2.18	6.27	1.115	- .794

[a]Normalized by ρc (free space impedance).
[b]Off optimum by choice $\theta = 2\,\theta_{opt}$

The liner design given in table IV has two sections with frequencies of peak attenuation of 502 and 3011 hertz. The number was chosen based on the shape of the target spectrum. The program calculated the particular frequencies. The value of H used here was chosen in order to achieve low η and large L/H and thus increased liner effectiveness. This duct height could be achieved by placing a single splitter ring in the existing QF-9 duct and expanding the outer casing by the thickness of the splitter.

A design estimate attenuation spectrum as well as the target attenuation for this liner is presented in figure 19. At the lower frequency tuning, a somewhat broader banded liner than the optimal case was considered advantageous in the interest of broadening the bandwidth without prohibitive length penalties. Therefore the resistance ratio at the peak frequency was selected at $\theta/\theta_{opt} = 2$. This, however, had an adverse effect on the peak attenuation. The magnitudes of the peak and of the bandwidth were determined from figures 15 to 18.

Recall that in the design procedure it is assumed that the surfaces which face each other in the duct are treated with identical materials. There can, however, arise practical considerations, both from a flow and a layout point of view which favor the staggering of materials. For example, as in the present design illustration, a low frequency tuning requires a large cavity depth, which would lead to a large splitter thickness. Thick splitters decrease inlet pressure recovery, and they are thus undesirable. Therefore it is most convenient to place such low frequency treatment on the outside and inside walls, and not on the splitter. Calculations for such a case have shown that as long as opposing walls are treated at frequencies which are reasonably close, there will be no significant differences from the case with opposing walls the same. Proper account must be taken of the required total area of each acoustic liner, as calculated by the analysis. Placing treatment on only one wall of a passage, in effect, would require approximately doubling the length of that treatment, for example. One is, in effect, moving the treatment from the splitter to the outer and inner walls. The placement of low frequency treatment on only outer and inner walls can be done only if there is either one or no splitters because if there were more than one splitter, there would occur a passage without any low frequency treatment.

Phase 2 - Mechanical Design

The value of optimum impedance required to give the predicted sound attenuation is calculated using the theoretical propagation model of Rice (ref. 15). Once the required value of acoustic liner impedance (e.g., optimum or off-optimum per choice) has been specified, the mathematical model relating impedance to the geometric parameters can be used to calculate open area ratio σ and backing depth b. The basic equations of the impedance model which are semiempirical were reported by Groeneweg in reference 22. However, these equations did not include the effect of the free stream steady flow on the impedance. In the present model empirical terms are added to account for this effect on specific resistance and reactance. The details of this mean flow effect are taken from reference 23. The following resistance equation is used to calculate the open area ratio σ:

$$\sigma = \frac{\beta + \sqrt{\beta^2 + 4\theta \frac{4\sqrt{2}}{3\pi} \frac{p_a}{\rho c^2 |Z|}}}{2\theta} \tag{25}$$

where

$$\beta = \frac{\sqrt{8\nu\omega}}{c}\left(1 + \frac{t}{d}\right) + 0.3|M_\infty| \tag{26}$$

$$Z = \sqrt{\theta^2 + \chi^2} \tag{27}$$

$$p_a = p_{ref}\ 10.^{OASPL/20.} \tag{28}$$

and where t is facing plate thickness, d is hole diameter in the facing plate, ν is kinemamatic viscosity, ω is circular frequency at the liner peak attenuation frequency ($\omega = 2\pi f_p$), ρ is air density, M_∞ is flowby Mach number (negative in the inlet and positive in the exhaust duct), and p_{ref} is the standard reference pressure used in calculating sound pressure level (2×10^{-4} Mbar), and OASPL is the duct overall sound pressure level. A reasonable estimate for the OASPL in-duct can be computed by assuming that acoustic energy is conserved between the duct and the far field. The far field energy can be assumed distributed uniformly over the duct cross section and the OASPL can be computed thereby.

The cavity depth (backing depth) b is found by solving the following reactance equation:

$$b = \frac{c}{\omega} \arctan \frac{\sigma c}{(t + \delta)\omega - \chi \sigma c} \tag{29}$$

where δ is an inertial end correction for the air in the hole of the facing sheet; that is,

$$\delta = \frac{0.85d\,(1. - 0.7\sqrt{\sigma})}{1. + 305.\,|M|^3} \tag{30}$$

where M_∞ is the duct free stream Mach number.

In the previous equations most of the terms are evaluated by a knowledge of flow conditions in the duct. Quantities which as yet appear unspecified are sheet thickness t and hole diameter d; there are no "equations" to calculate them. They are therefore set by alternate considerations, such as the nature of the environment, tuning frequency, availability of materials, and ease of fabrication. The nature of installation or environment (e.g., high temperature flow) may set a minimum thickness t. The tuning frequency, if very low, may require a very thick facing plate or even inset tubes, as used in reference 24, in order to keep the backing depth reasonably small so the suppressor will fit into available space and/or minimize aerodynamic pressure losses if used on a splitter ring.

Table V presents the open areas and backing depths, as well as the input sheet thicknesses and hole sizes for a liner in continuation of the example of the previous sections and described in table IV. Liner section 1 has a large backing depth, hole di-

TABLE V. - LINER MECHANICAL DESIGN, EXAMPLE LINER OF TABLE IV, FOR QF-9 DUCT

Section	Sheet thickness, t		Hole diameter, d		Open area ratio, σ, percent	Back cavity depth, b	
	cm	in.	cm	in.		cm	in.
1	3.8	1.5	0.64	0.25	23.7	7.06	2.779
2	.051	.020	.127	.050	12.0	1.37	0.541

ameter, and sheet thickness because of the low frequency of peak attenuation and the fact that exhaust ducts ($M > 0$) generally require larger backing depths than inlets require. The large thickness can be simulated with reasonably light weight by welding tubes of the required length to the back side of the facing sheet as was done in reference 24. This problem does not occur in liner section 2.

Appendix B contains a listing and a discussion of the liner design FORTRAN IV program. Also tabulated with the listing is a sample output of the program for the example problem carried through the report. The typical run time required for the program is less than a minute on the IBM 7094 computer.

Design Chart Based on Propagation and Impedance Models

The optimum impedance computed by the propagation model can be combined with the impedance model to give design charts as a function of f_p, η, environmental parameters such as duct static pressure p and temperature T, and other geometric variables of the liner. This design chart is not intended to replace the computations required by the preceding design methodology. Rather, the chart is an illustrative example of the trends contained within the calculation procedure. Of course, to cover all cases of interest, many charts would be needed.

An example of such charts is presented in figure 20 where the back-cavity depth is shown as a function of dimensionless frequency parameter η at selected values of frequency f_p, and the open area ratio σ is also given. Each of the parameters tabulated there also has a determinant effect on the chart, thus a new chart would be required if any one of these parameters were changed. As a point of reference, the locus of points for a constant H of 0.305 meter (1 ft) is included in figure 20(a). This locus is determined by connecting the points on the various curves for b at different frequencies, noting the interdependence of H, f_p, and η through the definition of η. All points to the right of the constant H curve have values of $H > 0.305$ meter (1 ft), and all points to the left have values of $H < 0.305$ meter (1 ft). This curve emphasizes the point that f_p and η are not independent if H is specified.

The curves of figure 20(b) show that, over a wide frequency range, required open area ratio does not vary significantly, once frequency has been accounted for through the frequency parameter η. The tolerance on the value of σ after fabrication is certainly much wider than the variation of design σ with f_p in the curves shown.

Comparison of Calculated Liner Performance with Experimental Results

An idea of how well the present design procedure works in estimating attenuation can be gained by comparing an attenuation estimate with some recent experimental results. At present there have not yet been tested any suppressors which were designed in accordance with the present procedures. Therefore it is necessary to use the data which are available from an existing design and make a performance estimate for the case tested. Recall that a set of unpublished data from the QF-1A program was used to specify the empirical constant in the design procedure. Obviously these data should be in good agreement with estimates made by the design procedure. This point was demonstrated by figure 13. Other data using the same inlet liner, but mounted on different fans, have shown similarly good agreement. As pointed out in an earlier section, further comparisons are needed in order to establish more confidence in the estimating procedure used here. The inlet had treated splitter rings in place, similar to those shown in figure 1 on another fan. Obviously the engine had no centerline drive shaft. In order to make the performance estimate for this inlet, the duct formed by the outer wall and the outermost ring was analyzed. Thereby the assumption was made that the inner passages were performing at least as well as the outer one and that the behavior in the outer passage dominated the far field results. The description of this outer passage is given in table VI. As seen in the table, the suppressor had two different sections, and each section was calculated to be off-optimum by the present design procedure.

Selected for consideration is a set of data (not related to the examples discussed elsewhere in this report) from the General Electric Quiet Engine C Program. The engine and nacelle are described in reference 25; however, the data used here are unpublished results from tests performed at the NASA Lewis Research Center.

TABLE VI. - SPECIFICATIONS OF GENERAL ELECTRIC, ENGINE C INLET LINER FOR FIGURE 21

[Duct Mach number, M, -0.4; duct temperature, T, 288 K (519° R); static pressure, p, 9.66×10^{4} N/m^2 (14.1b/$in.^2$); duct height, H, 15 cm (5.9 in.); sheet thickness, t, 0.081 cm (0.032 in.); hole diameter, d, 0.127 cm (0.050 in.).]

Open area ratio, σ, percent	Back cavity depth, b		Length, L		Peak frequency, f_p, Hz	Resistance ratio, θ/θ_{opt}
	cm	in.	cm	in.		
10	2.54	1.0	51.	20	1064	3.44
7	.76	.30	43.	17	2385	.81

The data were taken in such a way as to examine the effect of the inlet liner on attenuation at takeoff engine speed, forward maximum noise angle, and 61-meter (200-ft) sideline. The experimental attenuation spectrum was found by comparing the SPL spectra for the hard inlet baseline and the fully treated inlet. Both configurations had a full aft duct suppressor such that aft-radiated internal sound should not be a contributor at the forward angle of maximum noise.

The comparison between the measured attenuation and the estimated performance curve is shown in figure 21. The comparison is seen to be excellent, except at very low frequencies and at the tone, as was the case in figure 13.

While the data and the predicted curves presented in figures 13 and 21 show excellent agreement, further comparisons of this nature are required in order to gain more confidence in the prediction method.

CONCLUDING REMARKS

This report presents a design package for acoustic liners for turbofan engines. The procedure is comprised of an estimate of the noise output of the fan, a goal noise spectrum and attendant target attenuation spectrum, and finally a liner specification based upon the calculated target spectrum. The procedure is limited to the fan alone and does not consider other noise sources in the target attenuation estimate.

There are no experimental results yet available for a liner designed according to the present design procedure. However, a rough comparison was made between a performance estimate and measured attenuation for an engine inlet suppressor. In view of the fact that the measured data were probably approaching a noise floor, and the liner was off optimum according to the present model, the comparison is reasonable.

The design procedure for acoustic liners was developed from results of theoretical studies of wave propagation in acoustically treated ducts and from experimental results of full-scale fan and engine tests. The procedure applies only for annular flow passages as opposed to open cylindrical ducts. This limitation is a result of the fact that experimental data on cylindrical ducts are not well correlated by current theoretical models. The probable cause is spinning modes which come into play in cylindrical ducts and which have been analyzed only recently. Further work is needed to reconcile these recent analyses with measured results. Considerable effort would probably be involved, but the payoff would be an expansion of the design procedure to handle cylindrical ducts.

Because experimental results are incorporated into the procedure, it can be assumed that a number of real-world effects are included that are neglected or approximated in most theoretical studies. Additional comparisons between measured data and the correlation used in the present procedure are needed to verify and refine the empirical adjustment to the theoretical peak attenuation curves.

As presented, the procedure has its greatest utility in generating a number of candidate suppressor designs useful for tradeoff evaluations. A selected final design would be subjected to considerations that are less generalized than those presented in this procedure. It has been pointed out that updated behavior for all of the various factors can be incorporated as they are needed or become available. This is an important consideration because it is recognized that the design of suppressors is relatively in its infancy. It is inevitable that new and better information will become available.

Lewis Research Center,
National Aeronautics and Space Administration,
Cleveland, Ohio, August 19, 1975,
505-03.

APPENDIX A

NOISE ESTIMATING PROGRAM DESCRIPTION

Description

This computer program estimates the noise generation by a turbofan and uses it to establish target attenuation spectra required to reach a set noise target. Input data consist of basic geometric and flow information about the fan, as well as atmospheric conditions, and the noise target information. The printed and punched output results include spectral data for the various components of the noise estimate and the goal attenuation spectra at forward and rear angles. In adjusting the separate parts of the estimate to a desired location, spherical divergence, and atmospheric absorption are taken into account.

The main program and required subroutines are listed in this appendix, using FORTRAN IV computer language. The required data input cards are itemized in detail as comment cards at the beginning of the main program. Therefore, specific input requirements will not be discussed here.

The printed output resulting from this program is given in tables VII to XVIII. The numbers refer to example printout pages included after the main program and subroutines. The example shown is for the case carried throughout the main body of the report.

This program also produces punched output which is compatible with the liner specification program input requirements. These punched cards include the variables which are explained on comment cards in the liner specification program, appendix B: two throwaway explanatory cards, ISTART, ISTOP, GOAL(I), NF, SPL(I), SLJET(I), COND(I), and OASPL for both front and rear angles. The cards are arranged with all of the previous information punched for the front and then for the rear in block form.

```
$IBFTC WHLTNG
C
C       THIS PROGRAM ESTIMATES FAN NOISE SPECTRA AT 50 AND 120 DEGREES AND
C       DETERMINES GOAL ATTENUATION SPECTRA TO REACH A TARGET PNL.
C
C       BASIC FAN OPERATING PARAMETERS, DISTANCE, AND THE PNL TARGET
C       ARE RRQUIRED FOR THESE ESTIMATES.
C
C       A PREDICTED SPECTRUM CONSISTS OF DISCRETE TONES AND BROAD BAND NOISE
C       PREDICTED VIA A MODIFIED SMITH AND HOUSE PROCEDURE AND OF JET NOISE PREDI
C       CTED VIA A MODIFIED SAE PROCEDURE.
C
C       DATA REQUIRED
C         XPLN1(I)                                  12A6
C           CARD TO EXPLAIN FAN BEING PREDICTED
C         XPLN2(I)                                  12A6
C           SECOND CARD TO EXPLAIN FAN BEING PREDICTED
C         FLOW, VR, SOC, RPM, ROTORB, AMC           6F10.0
C           FLOW = FAN FLOW RATE, LB/SEC
C           VR = FAN-AIR TIP RELATIVE VELOCITY, FT/SEC
C           FOR THE CASE OF NO IGV'S, THIS IS ASSUMED TO BE TIP ROTATIVE SPEED.
C           SOC = ROTOR-STATOR AXIAL GAP (SPACING) DIVIDED BY ROTOR TIP
C               AXIAL CHORD.
C           RPM = FAN ROTATIVE SPEED
C           ROTORB = NUMBER OF ROTOR BLADES
C           AMC = ROTOR- STATOR MEAN AXIAL TIP CHORD, INCHES
C         VJ, AJ, AH                                3F10.0
C           VJ = JET VELOCITY, FT/SEC
C           AJ = NOZZLE AREA, SQUARE FEET
C           AH = NOZZLE CHARACTERISTIC LENGTH (ANNULUS HEIGHT), INCHES
C         DKIND, AKIND                              10X,A1,9X,A5
C           DKIND = BLANK OR S, FOR RADIUS OR SIDELINE CALCULATIONS, RESPECTIVELY
C           AKIND = BLANK OR NOATM, FOR ATM ATTN OR NOT, RESPECTIVELY
C         DIST, T, RH                               3F10.0
C           DIST = RADIUS OR SIDELINE DISTANCE, FEET
C           T = TEMP, DEGREES F, FOR ATM ATTN.
C           RH = RELATIVE HUMIDITY, PERCENT, FOR ATM ATTN.
C         AF, AR                                    2F10.0
C           AF = APPROX INLET FLOW AREA, SQUARE FEET.
C           AR = APPROX AFT DUCT AREA, SQUARE FEET.
C           THESE VARIABLES ARE USED FOR CALCULATION OF IN-DUCT OASPLS, AND
C           NEED BE SPECIFIED ONLY APPROXIMATELY FOR SUFFICIENT ACCURACY.
C         PNL                                       F10.0
C           PNL = TARGET PERCEIVED NOISE LEVEL AT CONDITION SPECIFIED BY
C                 DKIND AND DIST
C
C       THE ABOVE SET OF DATA IS FOR ONE FAN CALCULATION, FOR A NEW FAN A SINGLE
C       COMPUTER RUN CAN BE USED, BY ADDING ANOTHER SET OF DATA CARDS.
C
C       SUBROUTINES REQUIRED
C         TONES
C         BROAD
C         JET
C         GOAL
```

```
C         ATMSPR
C         BASPAT
C         ATMAT
C         SIDLAT
C         TOGTHR
C         COMPAR
C         PNDBER
C         XPLANE
C
      COMMON /FREQ/ F(27)
      COMMON /CONSTS/ NF,RPM,ROTORB,FLOW,VR,AMACHF,AMACHR,SOC
      COMMON /COND/ DKIND,AKIND,T,RH,DIST
      COMMON /PARTS/ STONE(27,2),SBROAD(27,2),SJET(27,2)
      COMMON /MANY/ N,ITONE(27)
      COMMON /CHORD/ AMC
      COMMON /DELF/ AMACHN
      COMMON /MESSG/ AMESSG
      COMMON /ANGLES/ ANG1,ANG2
      COMMON /XPLAN/ XPLN1(15),XPLN2(15)
      DIMENSION SGOAL(27),SATTN(27,2),SL(27,2)
      DIMENSION FU(27)
      DIMENSION ANGL(2)
      NAMELIST /NM1/ FLOW,VR,SOC,RPM,ROTORB,AMC,VJ,AJ,AH,DKIND,DIST,AKIN
     1D,T,RH,PNL,AMACHF,AMACHR
      DATA (FU(I),I=1,27)/50.,63.,80.,100.,125.,160.,200.,250.,315.,400.
     1,500.,630.,800.,1000.,1250.,1600.,2000.,2500.,3150.,4000.,5000.,63
     200.,8000.,10000.,12500.,16000.,20000./
      DATA AMESS1,AMESS2 /6HTOTAL ,6H   JET/
      DATA DTEST, ATEST /1HS,5H     /
      DATA SIDEL,RAD /4HSIDE,6HRADIUS/
      DATA FRNT,RER /5HFRONT,4HREAR/
      NF=24
      DO 1 I=1,27
1     F(I)=FU(I)
      ANG1=50.
      ANG2=120.
      ANGL(1)=ANG1
      ANGL(2)=ANG2
1005  CONTINUE
      READ (5,2) (XPLN1(I),I=1,12)
2     FORMAT (12A6)
      READ (5,2) (XPLN2(I),I=1,12)
      READ (5,10) FLOW, VR, SOC, RPM, ROTORB, AMC
10    FORMAT (6F10.0)
      READ (5,11) VJ,AJ,AH
11    FORMAT (3F10.0)
      READ (5,12) DKIND,AKIND
12    FORMAT (10X,A1,9X,A5)
      READ (5,109) DIST,T,RH
109   FORMAT (3F10.0)
      READ (5,1090) AF,AR
1090  FORMAT (2F10.0)
      READ (5,110) PNL
110   FORMAT (F10.0)
```

```
C
C     END OF INPUT DATA READING
C
      WRITE (6,1000)
 1000 FORMAT (1H1)
      WRITE (6,120)
 120  FORMAT (60X,10HINPUT DATA//)
      WRITE (6,1200) (XPLN1(I),I=1,12)
      WRITE (6,1200) (XPLN2(I),I=1,12)
 1200 FORMAT (35X,12A6//)
      WRITE (6,121) FLOW,VR,SOC,RPM,ROTORB,AMC
 121  FORMAT (35X,6F10.1//)
      WRITE (6,122) VJ,AJ,AH
 122  FORMAT (35X,3F10.2//)
      WRITE (6,123) DKIND,AKIND
 123  FORMAT (45X,A1,9X,A5//)
      WRITE (6,1230) DIST,T,RH
 1230 FORMAT (35X,3F10.1//)
      WRITE (6,1231) AF,AR
 1231 FORMAT (35X,2F10.1//)
      WRITE (6,124) PNL
 124  FORMAT (35X,F10.2)
      WRITE (6,1000)
      AMACHN=VR/1116.
C
C     CALCULATE INDIVIDUAL SPECTRUM COMPONENTS.
C
      CALL TONES (N,ITONE,STONE)
      CALL BROAD (SBROAD)
      CALL JET (AJ,AH,VJ,SJET)
C
C     NOW ASSEMBLE THE COMPONENTS AND ADJUST TO DESIRED SIDELINE OR RADIUS.
C
      CALL TOGTHR (NF,NA,SL,OASPLF,OASPLR)
      AMESSG=AMESS1
      CALL ATMSPR(SL)
      DO 15 J=1,2
      CALL PNDBER (1,NF,SL(1,J),PNDB1,PNDB2)
      GO TO (13,14), J
 13   PNDBF=PNDB1
      GO TO 15
 14   PNDBR=PNDB1
 15   CONTINUE
      WRITE (6,101)
 101  FORMAT (1H0//////////)
      WRITE (6,102)
 102  FORMAT (50X,25HPREDICTED HARD WALL PNL'S//)
      CALL XPLANE
      WRITE (6,103) PNDBF
 103  FORMAT (60X,8HPNDBF = ,F5.1//)
      WRITE (6,104) PNDBR
 104  FORMAT (60X,8HPNDBR = ,F5.1//)
      IF (DKIND .EQ. DTEST) DUMD=SIDEL
      IF (DKIND .NE. DTEST) DUMD=RAD
```

```
      WRITE (6,1040) DIST,DUMD
 1040 FORMAT (55X,3HAT ,F5.0,5H FEET,1X,A6)
      WRITE (6,1000)
      AMESSG=AMESS2
      CALL ATMSPR(SJET)
      CALL GOAL (PNL,NF,SGOAL)
      CALL COMPAR (NF,PNL,DIST,SGOAL,SJET,SL,SATTN)
C
C       CALCULATE IN-DUCT OASPL'S
C
      PI=3.1415927
      RSTD=100.
      R1=RSTD/SIN(PI*50./180.)
      R2=RSTD/SIN(PI*60./180.)
 205  CONTINUE
      ODF=OASPLF+10.*ALOG10(4.*PI*R1*R1/AF)
      ODR=OASPLR+10.*ALOG10(4.*PI*R2*R2/AR)
      WRITE (6,1001)
 1001 FORMAT (1H0////)
      WRITE (6,206) ODF,ODR
 206  FORMAT (55X,17HIN-DUCT OASPLF = ,F10.1/
     163X,9HOASPLR = ,F10.1)
      WRITE (6,1000)
      DO 210 J=1,2
      FRER=FRNT
      IF (J .EQ. 2) FRER=RER
      PUNCH 2060, FRER, (XPLN1(I),I=1,12)
 2060 FORMAT (13A6)
      PUNCH 2060, (XPLN2(I),I=1,12)
      ISTART=1
      ISTOP=NF
      DO 2063 I=1,NF
      I=I
      IF (ISTART .GT. 1) GO TO 2061
      IF (SATTN(I,J) .GE. 0. .AND. SATTN(I+1,J) .GT. 0.) ISTART=I
      ITEST=ISTART+3
 2061 CONTINUE
      IF (SATTN(I,J) .GT. 0. .AND. SATTN(I+1,J) .LE. 0.) ISTOP=I
      IF (ISTOP .LE. ITEST) ISTOP=NF
      IF (SATTN(I,J) .LT. 0. .AND. I .LT. ISTOP) ISTART = 1
 2063 CONTINUE
      PUNCH 2065, ISTART,ISTOP
 2065 FORMAT (2I3,54X,12HISTART,ISTOP)
      PUNCH 208, (SATTN(I,J),I=ISTART,ISTOP)
      PUNCH 207, NF
 207  FORMAT (I3,57X,2HNF)
      PUNCH 208, (SL(I,J),I=1,NF)
 208  FORMAT (8F10.1)
      PUNCH 208, (SJET(I,J),I=1,NF)
      PUNCH 209, DIST,DUMD,ANGL(J)
 209  FORMAT (10X,3HAT ,F10.0,5H FEET,1X,A6,1X,F10.0,1X,7HDEGREES)
      GO TO (2090,2093), J
 2090 PUNCH 2091, ODF
 2091 FORMAT (F10.1,50X,5HOASPL)
      GO TO 210
 2093 PUNCH 2091, ODR
 210  CONTINUE
      NOCHNG=1
      IF (NOCHNG .EQ. 1) GO TO 1005
      STOP
      END
```

```
$IBFTC TONE
      SUBROUTINE TONES (N,ITONE,STONE)
C
C      CALCULATE TONES FOR BPF AND ITS HARMONICS, ACCORDING TO METHOD OF
C      SMITH AND HOUSE
C
C      PARAMETERS
C        N   NUMBER OF ONE THIRD OCTAVE BANDS CONTAINING TONES.
C        ITONE(I)   WHICH ONE THIRD OCTAVE BANDS CONTAIN TONES.
C        STONE  SOUND PRESSURES IN TONES AT VARIOUS FREQUENCIES.
C
      COMMON /FREQ/ F(27)
      COMMON /CONSTS/ NF,RPM,ROTORB,FLOW,VR,AMACHF,AMACHR,SOC
      COMMON /DELF/ AMACHN
      DIMENSION ITONE(27),STONE(27,2)
      FF=RPM*ROTORB/60.
      AN=F(NF)/FF
      N=AN+1.
      AN=N
      FTEST=AN*FF
      FACTR=2.**.1667
      FGOOD=FACTR*F(NF)
      IF (FTEST .GT. FGOOD) N=N-1
      IHARM=0
      ICNT=0
      TRM1=10.*ALOG10(FLOW)
      TRM2=50.*ALOG10(VR/1000.)
      TRMF=10.*ALOG10(1.-AMACHN)
      TRMR=10.*ALOG10(1.+AMACHN)
      TRM3=-10.*ALOG10(SOC)
      TRM3=-20.*ALOG10(SOC)
      PART=85.+TRM1+TRM2+TRM3
      DO 30 I=10,NF
      I=I
      FLO=F(I-1)*FACTR
      FUP=F(I)*FACTR
      PWRF=0.
      PWRR=0.
      IDUM=0
 19   AN=IHARM+1
      FTEST=AN*FF
      IF (FTEST .GT. FLO .AND. FTEST .LT. FUP) GO TO 20
      IF (IDUM) 30,30,21
 20   IHARM=IHARM+1
      IDUM=IDUM+1
      TRM4=-20.*ALOG10(AN)
      SLF=PART+TRMF+TRM4
      SLR=PART+TRMR+TRM4
      PWRF=PWRF+10.**(SLF/10.)
      PWRR=PWRR+10.**(SLR/10.)
      GO TO 19
 21   ICNT=ICNT+1
      STONE(ICNT,1)=10.*ALOG10(PWRF)
      STONE(ICNT,2)=10.*ALOG10(PWRR)
      ITONE(ICNT)=I
 30   CONTINUE
      N=ICNT
C
C      PRINT OUT TONE SPECTRA.
C
```

```
      WRITE (6,101)
 101  FORMAT (1H0)
      WRITE (6,100)
 100  FORMAT (47X,36HFAN BLADE PASSING TONE AND HARMONICS//)
      WRITE (6,110)
 110  FORMAT (44X,43HAT 100 FT. SIDELINE, AND 50 AND 120 DEGREES//)
      CALL XPLANE
      WRITE (6,102)
 102  FORMAT (53X,30H   FREQ     STONEF    STONER   //)
      DO 105 I=1,N
      I=I
      IFRQ=I
      IFR=ITONE(I)
 105  WRITE (6,106) F(IFR),STONE(IFRQ,1),STONE(IFRQ,2)
 106  FORMAT (50X,F10.0,2F10.1)
      WRITE (6,1000)
 1000 FORMAT (1H1)
      RETURN
      END
```

```
$IBFTC BROADS
      SUBROUTINE BROAD (SBROAD)
      COMMON /FREQ/ F(27)
      COMMON /CONSTS/ NF,RPM,ROTORB,FLOW,VR,AMACHF,AMACHR,SOC
      DIMENSION SBROAD (27,2)
      COMMON /CHORD/ AMC
      COMMON /DELF/ AMACHN
      DIMENSION B(4)
      DATA (B(I),I=1,3) /50.514,.88348,.99493/
C
C      THIS SUBROUTINE COMPUTES THE BROAD BAND NOISE SPECTRUM FOR A SINGLE
C      STAGE FAN ACCORDING TO THE SMITH AND HOUSE PROCEDURE
C      WITH THE EXCEPTION THAT THE DIRECTIONAL PROPERTIES
C      ARE ASSUMED TO BE GIVEN BOTH FRONT AND REAR BY THE FRONT END FACTOR.
C
C      ARGUMENT
C        SBROAD THE CALCULATED BROAD BAND SPECTRUM
C
      FPK=10000./AMC
      SPLPK=75.+10.*ALOG10(FLOW)+50.*ALOG10(VR/1000.)
      TRMF=10.*ALOG10(1.-AMACHN)
C
C
C
      TRMF2=10.*ALOG10(1.+AMACHN)
      SPLPK2=SPLPK+TRMF2
C
C
C
      SPLPK=SPLPK+TRMF
      SIGMA=B(3)
      A=B(1)
      FRC=B(2)
```

```
C
C      NOW GENERATE SPECTRUM
C
       DO 30 I=1,NF
       FR=F(I)/FPK
       ARG=ALOG10(FR/FRC)
       ARG=ARG/SIGMA
       ARG=ARG*ARG
       FIT=A*EXP(-ARG)
       DECR=FIT-50.
       SDUM=SPLPK+DECR
       SBROAD (I,1)=SDUM
C
C
C
       SDUM2=SPLPK2+DECR
 25    SBROAD(I,2)=SDUM
C25    SBROAD(I,2)=SDUM2
C
C
 30    CONTINUE
C
C      PRINT OUT FAN BROAD BAND SPECTRA.
C
       WRITE (6,101)
 101   FORMAT (1H0)
       WRITE (6,100)
       WRITE (6,110)
 110   FORMAT (44X,43HAT 100 FT. SIDELINE, AND 50 AND 120 DEGREES//)
 100   FORMAT (50X,29HFAN BROAD BAND NOISE SPECTRUM//)
       CALL XPLANE
       WRITE (6,102)
 102   FORMAT (58X,20H   FREQ     SBROAD  //)
       DO 105 I=1,NF
 105   WRITE (6,106) F(I),SBROAD(I,1)
 106   FORMAT (55X,F10.0,F10.1)
       WRITE (6,1000)
 1000  FORMAT (1H1)
       RETURN
       END
```

```
$IBFTC GOALL
       SUBROUTINE GOAL (PNL,NF,SGOAL)
C
C      CALCULATES A SPECTRUM, SGOAL, WHICH WILL YIELD A CONSTANT NOY CURVE
C      AS A FUNCTION OF FREQUENCY.
C      THIS IS ONE OBVIOUS EASY WAY TO SHOOT FOR A DESIRED PNL.
C
C      ARGUMENTS
C        PNL = DESIRED TARGET PERCEIVED NOISE LEVEL, PNDB.
C        NF = NUMBER OF FREQUENCY POINTS IN SPECTRUM
C        SGOAL = SPECTRUM GIVING DESIRED TARGET PNL
C
```

```
      COMMON /FREQ/ F(27)
      DIMENSION SGOAL (27)
      ANF=NF
      EX=(PNL-40.)/33.21
      SUMNOY=10.**EX
      ANOYC=SUMNOY/(.85+.15*ANF)
      DO 30 I=1,NF
      I=I
      AI=I
      IF (I .GT. 9) GO TO 25
      DB=(ALOG(ANOYC)/ALOG(10.))*(22.+AI)-2.5*AI+64.
      TEST=85.-2.*AI
      IF (DB .LT. TEST) GO TO 30
      DB64=100.+13.-1.4*AI
      GO TO 26
 25   TRM=.04*(AI-19.5)*(AI-19.5)
      DB64=100.-11.*EXP(-TRM*(1.+TRM))
 26   DB=(10./(ALOG(10.)*ALOG10(2.)))*ALOG(ANOYC/64.)+DB64
 30   SGOAL(I)=DB
      WRITE (6,101)
 101  FORMAT (1H0)
      WRITE (6,100) PNL
 100  FORMAT (45X,31HCONSTANT NOY SPECTRUM TO REACH ,F5.1,5H PNDB//)
      WRITE (6,110) ANOYC
 110  FORMAT (55X,15HCONSTANT NOY = ,F5.1//)
      WRITE (6,102)
 102  FORMAT (58X,20H   FREQ       SGOAL  //)
      DO 105 I=1,NF
 105  WRITE (6,106) F(I),SGOAL(I)
 106  FORMAT (55X,F10.0,F10.1)
      WRITE (6,1000)
 1000 FORMAT(1H1)
      RETURN
      END
```

```
$IBFTC ATMS
      SUBROUTINE ATMSPR(SL)
C
C      CALCULATE NOISE LEVELS AT A DESIRED RADIUS OR SIDELINE,
C      ACCOUNTING FOR INVERSE SQUARE AND ATMOSPHERIC ATTENUATION.
C
C      ASSUMES SL INPUT SPECTRA ARE AT A SIDELINE, WITH ATMOSPHERIC
C
C      ADJUSTED SPECTRA MAY BE AT DIST SIDELINE OR RADIUS
C        MAY OR MAY NOT HAVE ATMOSPHERE ACCOUNTED FOR IN ADJUSTING FROM RSTD
C        TO DIST.
C        DKIND AND AKIND ARE THE DETERMINING CONTROLS.
C
C      SUBROUTINES REQUIRED
C        SIDLAT
C        BASPAT
C        ATMAT
      COMMON /FREQ/ F(27)
      COMMON /COND/ DKIND,AKIND,T,RH,DIST
```

```
      COMMON /CONSTS/ NF,RPM,ROTORB,FLOW,VR,AMACHF,AMACHR,SOC
      COMMON /MESSG/ AMESSG
      DIMENSION AI(2),R(2),SINAT(2),TFA(27,2),SL(27,2)
      DIMENSION ATA(27)
      DIMENSION ROLD(2)
      DATA DTEST,ATEST /1HS,5HNOATM/
      DATA AI(1),AI(2) /50.,120./,NM/2/,NB/3/
      DATA ANSD, ANSA /6HRADIUS,3HATM/
      DATA SIDEL /4HSIDE/
      PI=3.1415927
      RSTD=100.
      SIN50=SIN(PI*50./180.)
      SIN60=SIN(PI*60./180.)
      R(1)=DIST/SIN50
      R(2)=DIST/SIN60
      IF (DKIND .EQ. DTEST) GO TO 10
      R(1)=DIST
      R(2)=DIST
 10   CONTINUE
      ROLD(1)=RSTD/SIN50
      ROLD(2)=RSTD/SIN60
 24   IF (AKIND .EQ. ATEST) GO TO 22
      DO 17 J=1,NM
 17   CALL BASPAT (SL(1,J),RSTD,NF,NB,T,RH,TFA(1,J),R(J),ATA)
      DEL50=R(1)-RSTD/SIN50
      DEL60=R(2)-RSTD/SIN60
      DO 20 I=1,NF
      SL(I,1)=SL(I,1)-TFA(I,1)*DEL50/1000.
 20   SL(I,2)=SL(I,2)-TFA(I,2)*DEL60/1000.
 22   CONTINUE
C
C      ADJUST LEVELS TO NEW SIDELINE OR RADIUS, INVERSE SQUARE.
C
      DO 27 I=1,NF
      DO 27 J=1,NM
 27   SL(I,J)=SL(I,J)-20.*ALOG10(R(J)/ROLD(J))
 26   CONTINUE
      DO 23 I=1,NF
      DO 23 J=1,NM
      IF (SL(I,J) .LT. 0.) SL(I,J)=0.
 23   CONTINUE
C
C      PRINT OUT ATMOSPHERIC ATTENUATION SPECTRA.
C
      WRITE (6,100)
 100  FORMAT (46X,37HATMOSPHERIC ATTENUATION PER 1000 FEET)
      WRITE (6,101)
 101  FORMAT (1H0)
      WRITE (6,110)
 110  FORMAT (44X,45HACCOUNTING FOR SPECTRUM SHAPE, FRONT AND REAR//)
      WRITE (6,102)
 102  FORMAT (53X,30H   FREQ     DELDBF    DELDBR   //)
      DO 105 I=1,NF
 105  WRITE (6,106) F(I),TFA(I,1),TFA(I,2)
 106  FORMAT (50X,F10.0,2F10.1)
      WRITE (6,1000)
 1000 FORMAT (1H1)
C
C      PRINT OUT PREDICTED SPECTRA
C
      WRITE (6,201) AMESSG
```

```
 201   FORMAT  (62X,A6//)
       WRITE  (6,200)  DIST
 200   FORMAT  (40X,21HPREDICTED SPECTRA AT ,F5.0,24H FT., 50 AND 120 DEGR
      1EES//)
       IF  (DKIND .EQ. DTEST)  DUMD=SIDEL
       IF  (DKIND .NE. DTEST)  DUMD=ANSD
       IF  (AKIND .EQ. ATEST)  DUMA=ATEST
       IF  (AKIND .NE. ATEST)  DUMA=ANSA
       WRITE  (6,202)  DUMD,DUMA
 202   FORMAT  (35X,21HDISTANCE CONDITION = ,A6,25H, ATMOSPHERE CONDITION
      1= ,A6//)
       CALL XPLANE
       WRITE  (6,203)
 203    FORMAT (53X,30H    FREQ        SPLF        SPLR    //)
       DO 205 I=1,NF
 205   WRITE  (6,206)  F(I),SL(I,1),SL(I,2)
 206   FORMAT  (50X,F10.0,2F10.1)
       WRITE (6,1000)
       RETURN
       END
```

```
$IBFTC TOGTH
       SUBROUTINE TOGTHR (NF,NA,SL,OASPLF,OASPLR)
C
C       ASSEMBLE THE VARIOUS PARTS OF THE SPECTRA.
C
       COMMON /PARTS/ STONE(27,2),SBROAD(27,2),SJET(27,2)
       COMMON /FREQ/ F(27)
       COMMON /MANY/ N,ITONE(27),NF
       DIMENSION SL(27,2)
       NA=2
       DO 33 J=1,NA
       NCNT=1
       SUM=0.
       DO 30 I=1,NF
       I=I
       NWHICH=ITONE(NCNT)
       SND1=SBROAD(I,J)
       IF (I .EQ. NWHICH) GO TO 23
       GO TO 25
 23    SNDT=STONE(NCNT,J)
       NCNT=NCNT+1
       IF (SNDT .GT. SND1) SND1=SNDT
 25    SND2=SJET(I,J)
C
C       SUM IS USED IN OASPL CALCULATION.
C
         SUM=SUM+10.**(SND1/10.)
       ASND=10.**(SND1/10.)+10.**(SND2/10.)
       SND=10.*ALOG10(ASND)
 30    SL(I,J)=SND
       GO TO (31,32), J
 31    OASPLF=10.*ALOG10(SUM)
       GO TO 33
```

```
 32    OASPLR=10.*ALOG10(SUM)
 33    CONTINUE
C
C       PRINT OUT COMBINED SPECTRA AT 100 FEET SIDELINE.
C
C
       WRITE (6,101)
 101   FORMAT (1H0)
       WRITE (6,100)
 100   FORMAT (35X,61HCOMBINED FAN SPECTRA AT 100 FEET SIDELINE, 50 AND 1
      120 DEGREES//)
       CALL XPLANE
       WRITE (6,102) OASPLF,OASPLR
 102   FORMAT (37X,35HINTERNALLY GENERATED OASPL FRONT = ,F5.1,5X,7HREAR
      1= ,F5.1//)
       WRITE (6,103)
 103   FORMAT (53X,30H   FREQ      SPLF      SPLR   //)
       DO 105 I=1,NF
 105   WRITE (6,106) F(I),SL(I,1),SL(I,2)
 106   FORMAT (50X,F10.0,2F10.1)
       WRITE (6,1000)
 1000  FORMAT (1H1)
       RETURN
       END
```

```
$IBFTC COMPA
       SUBROUTINE COMPAR (NF,PNL,DIST,SGOAL,SJET,SL,SATTN)
C
C       COMPARE PREDICTED SPECTRA WITH TARGET SPECTRUM AND
C       DETERMINE REQUIRED ATTENUATION SPECTRA.
C
       COMMON /FREQ/ F(27)
       DIMENSION SGOAL(27),SL(27,2),SJET(27,2),SATTN(27,2)
       DO 25 J=1,2
       DO 25 I=1,NF
       IF (SGOAL(I) .LT. SJET(I,J)) GO TO 23
       SOFF=SGOAL(I)
       GO TO 25
 23    SOFF=SJET(I,J)
 25    SATTN(I,J)=SL(I,J)-SOFF
       WRITE (6,101)
 101   FORMAT (1H0)
       WRITE (6,100)
 100   FORMAT (45X,37HATTENUATION SPECTRA REQUIRED TO REACH//)
       WRITE (6,102) PNL,DIST
 102   FORMAT (48X,F5.1,9H PNDB AT ,F5.0,14H FEET SIDELINE//)
       CALL XPLANE
       WRITE (6,103)
 103   FORMAT (53X,30H   FREQ     SATTNF    SATTNR  //)
       DO 105 I=1,NF
 105   WRITE (6,106) F(I),SATTN(I,1),SATTN(I,2)
 106   FORMAT (50X,F10.0,2F10.1)
       RETURN
       END
```

```
$IBFTC PNDBRR
      SUBROUTINE PNDBER (I1,I2,DB,PNDB1,PNDB2)
C
C      THIS SUBROUTINE COMPUTES THE PNL FOR SPECTRUM DB, WHICH IS AN ARRAY WITH
C      THE INDEX I CORRESPONDING TO THE NUMBERS OF THE THIRD OCTAVE BANDS.
C
C      ARGUMENTS
C        I1 = FIRST BAND TO BE CONSIDERED IN PNDB CALCULATION NORMALLY 1
C        I2 = LAST BAND
C        DB = ARRAY CONTAINING THE SPECTRUM WHOSE PNL IS TO BE CALCULATED
C        PNDB1 = PNL CALCULATED BY SMOOTHED CURVE FIT OF THE TABULAR
C          DATA
C        PNDB2 = PNL CALCULATED USING TABULAR DATA.
C
      DIMENSION DB1(9),DB10(9),DB64(15),DB50(10),DB(27)
      DATA (DB1(I),I=1,9)/63.6,59.7,56.2,53.,50.5,48.,45.6,44.5,43./
      DATA (DB10(I),I=1,9)/87.,85.,83.1,80.,79.2,78.,75.,75.,74./
      DATA (DB64(I),I=1,15)/112.,111.,109.,107.,106.,105.,103.,102.,101.
     1,100.,100.,100.,100.,100.,98./
      DATA (DB50(I),I=1,10)/91.,89.,87.,86.,86.,87.,88.,91.,94.,97./
      SUMN1=0.0
      SUMN2=0.0
      FMAX1=0.0
      FMAX2=0.0
      DO 50 I=I1,I2
      IF (I .GT. 15) GO TO 30
      EX=0.030103*(DB(I)-DB64(I))
      FN1=64.0*10.0**EX
      FN2=FN1
      IF (FN1 .GT. 15. .OR. I .GT. 9) GO TO 40
      EX=(DB(I)-DB1(I))/(DB10(I)-DB1(I))
      FNLOW=10.0**EX
      IF (FNLOW .LT. FN1) FN1=FNLOW
      FN2=FN1
      GO TO 40
 30   J=I-15
      DBC=DB50(J)
      EX=0.030103*(DB(I)-DBC)
      FN1=50.0*10.0**EX
      IF (DB(I) .GE. DBC) GO TO 35
      X=(DBC-DB(I))**3
      FN1=FN1*(1.0+0.0279*X/(1.0+0.6*X))
      FN2=FN1
      GO TO 40
 35   X=DB(I)-DBC
      ARG=0.2*3.1415927*X
      FS=SIN(ARG)
      COR=FS
      IF (X .GT. 10.0) GO TO 37
      COR=(3.5-0.275*X)*FS
      IF (X .LT. 3.0) COR=COR+0.6*X*(3.0-X)
 37   FN2=FN1*(1.0+0.01*COR)
 40   SUMN1=SUMN1+FN1
      SUMN2=SUMN2+FN2
      IF (FN1 .GT. FMAX1) FMAX1=FN1
      IF (FN2 .GT. FMAX2) FMAX2=FN2
 50   CONTINUE
      F1=0.85*FMAX1+0.15*SUMN1
      F2=0.85*FMAX2+0.15*SUMN2
      PNDB1=10.0*(4.0+ALOG10(F1)/0.30103)
      PNDB2=10.0*(4.0+ALOG10(F2)/0.30103)
      RETURN
      END
```

```
$IBFTC JET2
      SUBROUTINE JET(A,AH,VJ,SJET)
C
C      THIS SUBROUTINE CALCULATES JET NOISE 1/3 OCTAVE SPECTRA AT 50 AND 120
C        DEGREES (SJET(I,1) AND SJET(I,2) RESPECTIVELY) ON A 100 FT. SIDELINE.
C
C      CALLS BASPAT AND ASSOCIATED SUBROUTINES.
C
C      ARGUMENTS
C        A = NOZZLE AREA, SQUARE FEET.
C        AH = JET CHARACTERISTIC LENGTH, INCHES
C        VJ = JET EXIT VELOCITY, FT/SEC
C        SJET = JET SPECTRA, DB
C
      COMMON /FREQ/ F(27)
      COMMON /COND/ DKIND,AKIND,T,RH,DIST
      COMMON /CONSTS/ NF,RPM,ROTORB,FLOW,VR,AMACHF,AMACHR,SOC
      COMMON /ANGLES/ ANG1,ANG2
      COMMON /SPECTR/ SJ(27,2)
      DIMENSION DI(16),ANG(16)
      DIMENSION SJET(27,2)
      DIMENSION OAJET(2)
      DIMENSION B(5)
      DIMENSION ATA (27), R(2)
      DIMENSION TFA(27,2)
      DATA BK1,BK2/.05,1./,NDG/4/
      DATA AO,A1/19.9,26.3/
      DATA BO /-4.7515/, (B(I),I=1,4) /.60049,-22.942,4.315,11.146/
      DATA CO,C1/-10.8,-15.82/
      DATA (DI(I),I=1,16) /-7.4,-6.8,-6.3,-5.7,-5.2,-4.4,-3.6,-2.7,-1.8,
     1-1.,0.,.8,1.8,3.1,4.5,6./,REFDI /2.5/, REFANG /135./
      DATA (ANG(I),I=1,16) /10.,20.,30.,40.,50.,60.,70.,80.,90.,100.,110
     1.,120.,130.,140.,150.,160./
      PI=3.1415927
      RT=200.
      NB=3
      RSTD=100.
      COMTRM=93.*ALOG10(VJ)-182.2+10.*ALOG10(A)
      FIFTY=PI*ANG1/180.
      FORTYF=PI*REFANG/180.
      SIXTY=PI*ANG2/180.
      R(1)=DIST/SIN(FIFTY)
      R(2)=DIST/SIN(SIXTY)
      DOWN1=ANG1-.01
      DOWN2=ANG2-.01
      UP1=ANG1+.01
      UP2=ANG2+.01
      DO 10 I=1,16
      I=I
      IF (ANG(I) .GT. DOWN1 .AND. ANG(I) .LT. UP1) KEEP1=I
      IF (ANG(I) .GT. DOWN2 .AND. ANG(I) .LT. UP2) KEEP2=I
 10   CONTINUE
      ADJST1=DI(KEEP1)-REFDI
      ADJST2=DI(KEEP2)-REFDI
      OAJET(1)=COMTRM+20.*ALOG10(2.*SIN(FIFTY)/SIN(FORTYF))+ADJST1
      OAJET(2)=COMTRM+20.*ALOG10(2.*SIN(SIXTY)/SIN(FORTYF))+ADJST2
      THRDOC=10.*ALOG10(3.)
      FACTR=(AH/12.)/VJ
      DO 30 I=1,NF
      I=I
      STRHAL=F(I)*FACTR
      X=ALOG10(STRHAL)
```

```
      IF (STRHAL .GT. BK1) GO TO 20
      DECR=AO+A1*X
      GO TO 25
 20   SUM=BO
      IF (STRHAL .GT. BK2) GO TO 22
      X=X-ALOG10(.23)
      DO 21 IDG=1,NDG
      IDG=IDG
 21   SUM=SUM+B(IDG)*(X**IDG)
      DECR=SUM
      GO TO 25
 22   DECR=CO+C1*X
 25   SJET(I,1)=OAJET(1)+DECR-THRDOC
 30   SJET(I,2)=OAJET(2)+DECR-THRDOC
      DO 40 J=1,2
 40   CALL BASPAT (SJET(1,J),RT,NF,NB,T,RH,TFA(1,J),R(J),ATA)
C
C      COMBINED ADJUSTMENT (ATM ATTN) IN - TO 100 FOOT RADIUS AT 45
C      DEGREES, THEN OUT - TO 100 FOOT SIDELINE AT 50 AND 120 DEGREES.
C
      DO 50 I=1,NF
      SJET(I,1)=SJET(I,1)+TFA(I,1)*(RT/SIN(FORTYF)-RSTD/SIN(FIFTY))/1000
     1.
 50   SJET(I,2)=SJET(I,2)+TFA(I,2)*(RT/SIN(FORTYF)-RSTD/SIN(SIXTY))/1000
     1.
C
C      ADJUST JET SPECTRA TO DESIRED (DIST) SIDELINE.
C
      DO 60 I=1,NF
      SJ(I,1)=SJET(I,1)+TFA(I,1)*((RSTD-DIST)/SIN(FIFTY))/1000.
 60   SJ(I,2)=SJET(I,2)+TFA(I,2)*((RSTD-DIST)/SIN(SIXTY))/1000.
      DELDIS=20.*ALOG10(DIST/RSTD)
      DO 61 I=1,NF
      SJ(I,1)=SJ(I,1)-DELDIS
 61   SJ(I,2)=SJ(I,2)-DELDIS
C
C      PRINT OUT JET NOISE SPECTRA.
C
      WRITE (6,101)
 101  FORMAT (1H0)
      WRITE (6,100)
 100  FORMAT (56X,17HJET NOISE SPECTRA//)
      WRITE (6,110)
 110  FORMAT (44X,43HAT 100 FT. SIDELINE, AND 50 AND 120 DEGREES//)
      CALL XPLANE
      WRITE (6,102)
 102  FORMAT (53X,30H   FREQ       SJETF      SJETR   //)
      DO 105 I=1,NF
 105  WRITE (6,106) F(I),SJET(I,1),SJET(I,2)
 106  FORMAT (50X,F10.0,2F10.1)
      WRITE (6,1000)
 1000 FORMAT (1H1)
      RETURN
      END
```

```
$IBFTC BASPTT
      SUBROUTINE BASPAT(A,RT,NF,NB,T,RH,TFA,R,ATA)
C         CALLS ATMAT
      DIMENSION A(27),TFA(27),ATA(27)
      REAL M(27,2)
      NLS=NF-1
      DO 10 I=1,NLS
      M(I,2)=A(I+1)-A(I)
   10 M(I+1,1)=M(I,2)
      M(1,1)=M(1,2)
      M(NF,2)=M(NF,1)
      NS=3
      S=NS
      B=NB
      BI=B*2.0*FLOAT(NS)
      F1=1.0
      IF(NB.EQ.1)F1=10.0**1.8
      IF(NB.EQ.3)F1=10.0**1.7
      DO 30 I=1,NF
      FC=10.0**(0.3/B*FLOAT(I-1))*F1
      CALL ATMAT(T,RH,1000.0,FC,AC)
      SL=1.0
      SLA=10.0**(-AC/10.0)
      DO 20 K=1,NS
      XL=-K
      XR=K
      EL=M(I,1)/2.0*XL/S
      ER=M(I,2)/2.0*XR/S
      SL=SL+10.0**(EL/10.0)+10.0**(ER/10.0)
      FL=10.0**(0.3/BI*XL)*FC
      FR=10.0**(0.3/BI*XR)*FC
      CALL ATMAT(T,RH,1000.0,FL,AL)
      CALL ATMAT(T,RH,1000.0,FR,AR)
   20 SLA=SLA+10.0**((EL-AL)/10.0)+10.0**((ER-AR)/10.0)
      TFA(I)=10.0*ALOG10(SL)-10.0*ALOG10(SLA)
   30 ATA(I)=A(I)- TFA(I)*R/1000.0-20.0*ALOG10(R/RT)
      RETURN
      END
```

```
$IBFTC ATMATV
      SUBROUTINE ATMAT(T,RH,DIST,FREQ,ATT)
      DIMENSION A(22)
      DATA A/0.870,0.750,0.652,0.570,0.505,0.452,0.406,0.369,0.335,
     1 0.308,0.286,0.268,0.253,0.240,0.231,0.225,0.220,0.215,0.210,
     1 0.208,0.202,0.200/
      AC=(0.1*(FREQ/1000.0)**2.05)/(1.651-.00103*T)**2.05
      AMM=(10.0*(FREQ/1000.0)**1.003)/10.0**(0.52-.00504*(T+
     1 SQRT(256.0-(10.0-T/5.0)**2)))
      HA=0.25*RH/10.0**(1.493-.01638*T-.02*SQRT(128.2-(10.0-T/5.00)**2))
      HMM=10.0**(0.4973*ALOG10(FREQ)-1.4894)
      HH=HA/HMM
      IF(HH.GT.0.25)GO TO 10
      AA=1.2*HH
      GO TO 15
   10 IF(HH.GT.0.60)GO TO 11
      AA=1.543*HH-.086
      GO TO 15
```

```
   11 IF(HH.GT.0.95)GO TO 12
      AA=0.84+0.16*SIN(3.14159/2.0*(HH-0.6)/0.35)
      GO TO 15
   12 IF(HH.GT.1.25)GO TO 13
      AA=0.87+0.13*COS(3.14159/2.0*(HH-0.95)/0.3)
      GO TO 15
   13 IF(HH.GT.6.5)GO TO 14
      HTEST=1.25
      DO 16 I=2,22
      HTEST=HTEST+0.25
      IF(HH.LE.HTEST)GO TO 17
   16 CONTINUE
   17 AA=A(I)+((HTEST-HH)/0.25)*(A(I-1)-A(I))
      GO TO 15
   14 AA=0.2
   15 CONTINUE
      ATT=(AMM*AA+AC)*(DIST/1000.0)
      RETURN
      END
```

```
$IBFTC SIDLTT
      SUBROUTINE SIDLAT(NM,AI,RSTD,SIDIST,SINAT,RADIST)
      DIMENSION AI(19),SINAT(19),RADIST(19)
      F=3.1415927/180.0
      RSQ=20.0*ALOG10(SIDIST/RSTD)
      DO 10 J=1,NM
      ST=SIN(AI(J)*F)
      IF(ST.LE.0.0)GO TO 20
      SINAT(J)=RSQ-20.0*ALOG10(ST)
      RADIST(J)=SIDIST/ST
      GO TO 10
   20 SINAT(J)=0.0
      RADIST(J)=0.0
   10 CONTINUE
      RETURN
      END
```

```
$IBFTC XPLANY
      SUBROUTINE XPLANE
C
C      SIMPLE PRINT-OUT ROUTINE
C
      COMMON /XPLAN/ XPLN1(15),XPLN2(15)
      WRITE (6,3) (XPLN1(I),I=1,12)
 3    FORMAT (45X,12A6//)
      WRITE (6,3) (XPLN2(I),I=1,12)
      RETURN
      END
```

```
C
C     ..................................................................
C
C        SUBROUTINE ATSG
C
C        PURPOSE
C           NDIM POINTS OF A GIVEN GENERAL TABLE ARE SELECTED AND
C           ORDERED SUCH THAT ABS(ARG(I)-X).GE.ABS(ARG(J)-X) IF I.GT.J.
C
C        USAGE
C           CALL ATSG (X,Z,F,WORK,IROW,ICOL,ARG,VAL,NDIM)
C
C        DESCRIPTION OF PARAMETERS
C           X      - THE SEARCH ARGUMENT.
C           Z      - THE VECTOR OF ARGUMENT VALUES (DIMENSION IROW).
C           F      - IN CASE ICOL=1, F IS THE VECTOR OF FUNCTION VALUES
C                    (DIMENSION IROW).
C                    IN CASE ICOL=2, F IS AN IROW BY 2 MATRIX. THE FIRST
C                    COLUMN SPECIFIES THE VECTOR OF FUNCTION VALUES AND
C                    THE SECOND THE VECTOR OF DERIVATIVES.
C           WORK   - A WORKING STORAGE (DIMENSION IROW).
C           IROW   - THE DIMENSION OF VECTORS Z AND WORK AND OF EACH
C                    COLUMN IN MATRIX F.
C           ICOL   - THE NUMBER OF COLUMNS IN F (I.E. 1 OR 2).
C           ARG    - THE RESULTING VECTOR OF SELECTED AND ORDERED
C                    ARGUMENT VALUES (DIMENSION NDIM).
C           VAL    - THE RESULTING VECTOR OF SELECTED FUNCTION VALUES
C                    (DIMENSION NDIM) IN CASE ICOL=1. IN CASE ICOL=2,
C                    VAL IS THE VECTOR OF FUNCTION AND DERIVATIVE VALUES
C                    (DIMENSION 2*NDIM) WHICH ARE STORED IN PAIRS (I.E.
C                    EACH FUNCTION VALUE IS FOLLOWED BY ITS DERIVATIVE
C                    VALUE).
C           NDIM   - THE NUMBER OF POINTS WHICH MUST BE SELECTED OUT OF
C                    THE GIVEN TABLE (Z,F).
C
C        REMARKS
C           NO ACTION IN CASE IROW LESS THAN 1.
C           IF INPUT VALUE NDIM IS GREATER THAN IROW, THE PROGRAM
C           SELECTS ONLY A MAXIMUM TABLE OF IROW POINTS.  THEREFORE THE
C           USER OUGHT TO CHECK CORRESPONDENCE BETWEEN TABLE (ARG,VAL)
C           AND ITS DIMENSION BY COMPARISON OF NDIM AND IROW, IN ORDER
C           TO GET CORRECT RESULTS IN FURTHER WORK WITH TABLE (ARG,VAL).
C           THIS TEST MAY BE DONE BEFORE OR AFTER CALLING
C           SUBROUTINE ATSG.
C           SUBROUTINE ATSG ESPECIALLY CAN BE USED FOR GENERATING THE
C           TABLE (ARG,VAL) NEEDED IN SUBROUTINES ALI, AHI, AND ACFI.
C
C        SUBROUTINES AND FUNCTION SUBPROGRAMS REQUIRED
C           NONE
C
C        METHOD
C           SELECTION IS DONE BY GENERATING THE VECTOR WORK WITH
C           COMPONENTS WORK(I)=ABS(Z(I)-X) AND AT EACH OF THE NDIM STEPS
C           (OR IROW STEPS IF NDIM IS GREATER THAN IROW)
C           SEARCHING FOR THE SUBSCRIPT OF THE SMALLEST COMPONENT, WHICH
C           IS AFTERWARDS REPLACED BY A NUMBER GREATER THAN
C           MAX(WORK(I)).
C
C     ..................................................................
```

```
C
      SUBROUTINE ATSG(X,Z,F,WORK,IROW,ICOL,ARG,VAL,NDIM)
C
C     THIS SUBROUTINE HAS BEEN ALTERED TO HANDLE PATHOLOGICAL SITUATIONS SUCH
C     AS EXTRAPOLATIONS WITHIN, OR OUTSIDE, OF THE TABLE.  IF EXTRAPOLATION
C     OUTSIDE THE TABLE IS REQUIRED, NOIM ON RETURN IS REDUCED TO 2 AND A
C     STRAIGHT LINE THROUGH THE TWO CLOSEST POINTS IS USED TO DO THE
C     EXTRAPOLATION.  OTHERWISE ARG IS FORCED TO BRACKET THE VALUE OF X.
C
C
C
      DIMENSION Z(1),F(1),WORK(1),ARG(1),VAL(1)
      NSAVE=NDIM
      NDIM=IROW
      IF(IROW)11,11,1
    1 N=NDIM
C     IF N IS GREATER THAN IROW, N IS SET EQUAL TO IROW.
      IF(N-IROW)3,3,2
    2 N=IROW
C
C     GENERATION OF VECTOR WORK AND COMPUTATION OF ITS GREATEST ELEMENT.
    3 B=0.
      DO 5 I=1,IROW
      DELTA=ABS(Z(I)-X)
      IF(DELTA-B)5,5,4
    4 B=DELTA
    5 WORK(I)=DELTA
C
C     GENERATION OF TABLE (ARG,VAL)
      B=B+1.
      DO 10 J=1,N
      DELTA=B
      DO 7 I=1,IROW
      IF(WORK(I)-DELTA)6,7,7
    6 II=I
      DELTA=WORK(I)
    7 CONTINUE
      ARG(J)=Z(II)
      IF(ICOL-1)8,9,8
    8 VAL(2*J-1)=F(II)
      III=II+IROW
      VAL(2*J)=F(III)
      GOTO 10
    9 VAL(J)=F(II)
   10 WORK(II)=B
C
C      DO CALCULATION TO DETERMINE WHETHER X, THE SEARCH ARGUMENT, IS OUTSIDE
C      THE RANGE OF THE TABLE.  IF SO, EXTRAPOLATION IS REQUIRED AND THE
C      SIMPLEST TYPE OF CURVE, A STRAIGHT LINE, SHOULD BE USED IN ORDER TO
C      AVOID THE LIKELIHOOD OF UNREASONABLE RESULTS FROM A POLYNOMIAL OF
C      HIGHER DEGREE.
C
       ILT=1
       IGT=1
       DO 15 I=1,IROW
       IF (X .GT. Z(I)) ILT=0
       IF (X .LT. Z(I)) IGT=0
   15  CONTINUE
```

```
C
C        NOW, IF X IS GREATER THAN ANY ONE OF THE TABLE ARGUMENTS, ILT=0
C        NOW, IF X IS LESS THAN ANY ONE OF THE TABLE ARGUMENTS, TGT=0
C        HOWEVER, IF ILT REMAINS 1, THEN X IS LESS THAN ALL ARGUMENTS OF THE TABLE
C        IF IGT REMAINS 1, THEN X IS GREATER THAN ALL THE ARGUMENTS OF THE TABLE.
C        IN EITHER OF THE LATTER EVENTS, THE TWO CLOSEST VALUES FROM THE TABLE
C        SHOULD BE USED FOR THE EXTRAPOLATION, SINCE ARG IS ORDERED SUCH AS TO
C        BE AT INCREASING DISTANCES FROM X, ONE MERELY HAS TO LIMIT CONSIDERATION
C        TO THE FIRST TWO VALUES OF ARG AND VAL.
C
      IF (ILT. EQ. 1) GO TO 17
      IF (IGT .EQ. 1) GO TO 17
      GO TO 18
   17 NDIM=2
      RETURN
C
C        CHECK TO MAKE SURE THAT THE RANGE OF ARG BRACKETS X FOR THE CASE WHERE
C        X FALLS WITHIN THE RANGE OF THE TABLE OF ARGUMENTS, 2(I).
C        THIS IS TO AVOID UNNECESSARY EXTRAPOLATION WITHIN THE TABLE FOR CERTAIN
C        SPECIAL CASES OF THE SPACING OF Z(I).
C
   18 CONTINUE
      ILT=1
      IGT=1
      DO 21 I=1,NSAVE
      IF (X .GT. ARG(I)) ILT=0
      IF (X .LT. ARG(I)) IGT=0
   21 CONTINUE
      IF (ILT .EQ. 1) GO TO 23
      IF (IGT .EQ. 1) GO TO @(
      NDIM=NSAVE
      RETURN
   23 NSP1=NSAVE+1
      DO 25 I=NSP1,IROW
      IF (X .GT. ARG(I)) GO TO 26
   25 CONTINUE
      RETURN
   26 IWHICH=I
      ARG(NSAVE)=ARG(IWHICH)
      VAL(NSAVE)=VAL(IWHICH)
      NDIM=NSAVE
      RETURN
   29 NSP1=NSAVE+1
      DO 33 I=NSP1,IROW
      IF (X .LT. ARG(I)) GO TO 34
   33 CONTINUE
      RETURN
   34 IWHICH=I
      ARG(NSAVE)=ARG(IWHICH)
      VAL(NSAVE)=VAL(IWHICH)
      NDIM=NSAVE
   11 RETURN
      END
```

```
      SUBROUTINE LGRTRP (XX,YY,LIM,X,Y)
C
C      INTERPOLATE A FUNCTION VALUE Y AT DESIRED ARGUMENT VALUE X FROM A TABLE
C      OF VALUES YY (TABULATED Y) VERSUS XX (TABULATED X).
C
C      XX(I) MUST BE ARRANGED IN ORDER OF INCREASING DISTANCE FROM X AS I
C      INCREASES.
C      XX MUST BRACKET X, UNLESS EXTRAPOLATION IS CALLED FOR.
C      MODIFIED ATSG CAN BE USED TO ACCOMPLISH THESE ORGANIZATIONS PRIOR TO
C      CALLING LGRTRP.
C
C
C      DEFINITION OF PARAMETERS IN SUBROUTINE CALL
C        XX   ARRAY CONTAINING TABULATED ARGUMENT (X) VALUES
C        YY   ARRAY CONTAINING TABULATED FUNCTION (Y) VALUES
C        LIM   NUMBER OF XX VALUES IN THE TABLE
C        X   VALUE OF ARGUMENT AT WHICH FUNCTION VALUE IS DESIRED
C        Y   CALCULATED DESIRED FUNCTION VALUE.
C
C      METHOD IS LAGRANGE INTERPOLATION AS GIVEN ON P 215 OF NUMERICAL
C      METHODS AND COMPUTERS BY S.S. KUO, PUBLISHED BY ADDISON-WESLEY, 1965
C
      DIMENSION YY(12),XX(12)
      NDIM=LIM
    3 CONTINUE
      C=0.
      DO 52 I=1,LIM
      ZXI=XX(I)
      P=1.
      DO 40 J=1,LIM
      IF (I-J) 35,40,35
   35 ZXJ=XX(J)
      A=(X-ZXJ)/(ZxI-ZXJ)
      P=P*A
   40 CONTINUE
      B=P*YY(I)
      C=C*B
   52 CONTINUE
      Y=C
C
C      CHECK FOR RIDICULOUS RESULTS IN INTERPOLATION, USE STRAIGHT LINE
C      INTERPOLATION IF HIGHER ORDER INTERPOLATION GIVES VALUE OF Y WHICH IS
C      GREATER OR LESS THAN BOTH THE YYS AT THE NEAREST TWO XXS.  NOTE IF THE
C      FUNCTION IS KNOWN NOT TO BE MONATONIC, THEN THIS LOGIC SHOULD PROBABLY
C      BE DISABLED.
C
      IF (NDIM .EQ. 2) GO TO 82
      DELTA=X-XX(1)
      DO 72 I=2,LIM
      DELTA2=X-XX(I)
      IF (DELTA1 .LT. 0. .AND. DELTA2 .GT. 0.) GO TO 73
      IF (DELTA1 .GT. 0. .AND. DELTA2 .LT. 0.) GO TO 73
   72 CONTINUE
   73 IWHICH=I
      IF (Y .GT. YY(1) .AND. Y .GT. YY(IWHICH)) GO TO 75
      IF (Y .LT. YY(1) .AND. Y .LT. YY(IWHICH)) GO TO 75
      GO TO 82
   75 LTM=2
      XX (2)=XX(IWHICH)
      YY (2)=YY(IWHICH)
      GO TO 3
   82 CONTINUE
      LIM=NDIM
      RETURN
      END
```

Printed Output

The variable names used in the program output have been selected for clarity and ease of interpretation. In general the trailing letters "F" and "R" of a given name (e.g., STONEF) refer to the sound level at the forward and rear angles of maximum noise, respectively. Furthermore, the leading "S" stands for "sound". Thus STONEF is the name of the sound spectrum of tones at the forward and maximum angle. Otherwise symbolism should be self-explanatory. For example PR stands for pressure ratio and ATTN stands for attenuation.

The initial page of the output section is a set of input data in proper format to be used in running the program.

TABLE VII. - SET OF INPUT DATA-NOISE ESTIMATE

```
                  INPUT DATA
HAMILTON STANDARD 1.2 PR PROP-FAN (QF-9)
100 PERCENT SPEED, TAKEOFF BLADE-SETTING
   890.0     700.0       2.0    2227.0       15.0       12.5
   579.00    21.76     18.60
      S
   500.0      59.0      70.0
    25.0      25.0
    90.00
```

TABLE VIII. - CALCULATED BLADE PASSING TONE AND ITS HARMONICS

AT 30.5-METER (100-FT) SIDELINE AND 50^{o} AND 120^{o}

[Hamilton standard 1.2 PR prop-fan (QF-9); 100 percent speed; takeoff blade setting.]

FREQ	STONEF	STONER
500.	96.4	102.8
1000.	90.4	96.8
1600.	86.9	93.3
2000.	84.4	90.8
2500.	82.5	88.9
3150.	80.9	87.3
4000.	82.0	88.4
5000.	79.9	86.3
6300.	78.3	84.7
8000.	79.3	85.7
10000.	77.2	83.6

TABLE IX. - FAN BROADBAND SPECTRUM AT 30.5-METER (100-FT)

SIDELINE AND 50° AND 120°

[Hamilton standard 1.2 PR prop-fan (QF-9); 100 percent speed; takeoff blade setting.]

FREQ	SBROAD
50.	55.7
63.	59.0
80.	62.9
100.	66.8
125.	71.0
160.	75.6
200.	79.7
250.	83.6
315.	87.1
400.	90.0
500.	91.8
630.	92.8
800.	92.8
1000.	91.8
1250.	89.9
1600.	86.9
2000.	83.6
2500.	79.7
3150.	75.5
4000.	71.0
5000.	66.8
6300.	62.8
8000.	58.9
10000.	55.7

TABLE X. - JET NOISE AT 30.5-METER (100-FT) SIDELINE

AND 50° AND 120°

[Hamilton standard 1.2 PR prop-fan (QF-9); 100 percent speed; takeoff blade setting.]

FREQ	SJETF	SJETR
50.	76.2	83.2
63.	77.1	84.2
80.	77.6	84.6
100.	77.6	84.6
125.	77.1	84.2
160.	76.3	83.3
200.	75.2	82.3
250.	73.9	81.0
315.	72.6	79.7
400.	71.2	78.2
500.	69.7	76.7
630.	68.1	75.2
800.	66.5	73.6
1000.	65.0	72.1
1250.	63.5	70.6
1600.	61.9	69.0
2000.	60.5	67.6
2500.	59.1	66.2
3150.	57.7	64.9
4000.	56.4	63.6
5000.	55.4	62.6
6300.	54.5	61.8
8000.	53.9	61.3
10000.	53.8	61.4

TABLE XI. - TOTAL SPECTRA AT 30.5-METER (100-FT) SIDELINE

AND 50° AND 120°

[Hamilton standard 1.2 PR prop-fan (QF-9); 100 percent speed; takeoff blade setting; internally generated forward OASPL, 101.5; internally generated rear OASPL, 105.7.]

FREQ	SPLF	SPLF
50.	76.2	83.3
63.	77.2	84.2
80.	77.7	84.7
100.	77.9	84.7
125.	78.1	84.4
160.	79.0	84.0
200.	81.1	84.2
250.	84.0	85.5
315.	87.2	87.8
400.	90.0	90.2
500.	96.5	102.9
630.	92.9	92.9
800.	92.8	92.9
1000.	91.8	96.8
1250.	90.0	90.0
1600.	87.0	93.3
2000.	84.4	90.8
2500.	82.5	88.9
3150.	80.9	87.3
4000.	82.0	88.4
5000.	79.9	86.4
6300.	78.3	84.7
8000.	79.3	85.7
10000.	77.2	83.6

TABLE XII. - ATMOSPHERIC ATTENUATION PER 305 METERS (1000 FT) FOR SPECTRA OF TABLE X (ACCOUNTING FOR SPECTRUM SHAPE, FRONT AND REAR)

FREQ	DELDBF	DELDBR
50.	0.1	0.1
63.	0.1	0.1
80.	0.1	0.1
100.	0.1	0.1
125.	0.2	0.2
160.	0.2	0.2
200.	0.3	0.3
250.	0.4	0.4
315.	0.5	0.5
400.	0.6	0.6
500.	0.7	0.7
630.	0.9	0.9
800.	1.2	1.2
1000.	1.5	1.5
1250.	1.9	1.9
1600.	2.3	2.4
2000.	3.1	3.1
2500.	4.1	4.1
3150.	5.6	5.6
4000.	7.7	7.7
5000.	10.8	10.8
6300.	15.6	15.6
8000.	22.4	22.4
10000.	31.7	31.7

TABLE XIII. - TOTAL SPECTRA FOR TARGET PNL AT

152.5-METER (500-FT) SIDELINE AND 50° AND 120°

[Hamilton standard 1.2 PR prop-fan (QF-9); 100 percent speed; takeoff blade setting; distance condition = side; atmospheric condition = atm.]

FREQ	SPLF	SPLR
50.	62.2	69.2
63.	63.1	70.2
80.	63.7	70.6
100.	63.9	70.7
125.	64.0	70.3
160.	64.9	69.9
200.	66.9	70.1
250.	69.9	71.3
315.	73.0	73.6
400.	75.7	76.0
500.	82.1	88.5
630.	78.4	78.5
800.	78.3	78.4
1000.	77.1	82.2
1250.	75.0	75.2
1600.	71.8	78.2
2000.	68.8	75.4
2500.	66.4	73.0
3150.	64.0	70.7
4000.	64.0	70.9
5000.	60.3	67.4
6300.	56.2	63.5
8000.	53.6	61.4
10000.	46.7	55.0

TABLE XIV. - HARD WALL PNL'S AT NOTED POINT

[Hamilton standard 1.2 PR prop-fan (QF-9); 100 percent speed; takeoff blade setting.]

PNDBF = 95.2

PNDBR = 100.5

AT 500. FEET SIDE

TABLE XV. - ATMOSPHERIC ATTENUATION SPECTRA PER 305 METERS (1000 FT) FOR JET NOISE SPECTRUM (ACCOUNTING FOR SPECTRUM SHAPE, FRONT AND REAR)

FREQ	DELDBF	DELDBR
50.	0.1	0.1
63.	0.1	0.1
80.	0.1	0.1
100.	0.1	0.1
125.	0.2	0.2
160.	0.2	0.2
200.	0.3	0.3
250.	0.4	0.4
315.	0.5	0.5
400.	0.6	0.6
500.	0.7	0.7
630.	0.9	0.9
800.	1.2	1.2
1000.	1.5	1.5
1250.	1.9	1.9
1600.	2.4	2.4
2000.	3.1	3.1
2500.	4.1	4.1
3150.	5.6	5.6
4000.	7.7	7.7
5000.	10.9	10.9
6300.	15.5	15.5
8000.	22.4	22.4
10000.	32.2	32.3

TABLE XVI. - JET SPECTRA FOR TARGET PNL AT 152.5-METER (500-FT) SIDELINE AND 50° AND 120°

[Hamilton standard 1.2 PR prop-fan (QF-9); 100 percent speed; takeoff blade setting; distance condition = side, atmospheric condition = atm.]

FREQ	SPLF	SPLR
50.	62.2	69.2
63.	63.1	70.2
80.	63.5	70.6
100.	63.5	70.6
125.	63.1	70.1
160.	62.2	69.3
200.	61.1	68.1
250.	59.8	66.9
315.	58.4	65.5
400.	56.9	64.0
500.	55.3	62.4
630.	53.6	60.8
800.	51.9	59.1
1000.	50.3	57.4
1250.	48.6	55.8
1600.	46.7	53.9
2000.	44.9	52.2
2500.	43.0	50.4
3150.	40.9	48.3
4000.	38.4	46.1
5000.	35.7	43.6
6300.	32.4	40.6
8000.	28.2	36.9
10000.	23.0	32.5

TABLE XVII. - CONSTANT NOY SPECTRUM REQUIRED

TO REACH PNL GOAL (90.0 PNdB)

[Constant Noy = 7.2.]

FREQ	SGOAL
50.	81.2
63.	79.6
80.	77.9
100.	76.3
125.	74.6
160.	73.1
200.	71.7
250.	70.3
315.	68.9
400.	68.5
500.	68.5
630.	68.5
800.	68.4
1000.	67.7
1250.	65.9
1600.	63.2
2000.	60.4
2500.	58.5
3150.	57.6
4000.	57.6
5000.	58.5
6300.	60.4
8000.	63.2
10000.	65.9

TABLE XVIII. - ATTENUATION SPECTRA REQUIRED TO REACH GOAL (90.0 PNdB) TOGETHER WITH ESTIMATED IN-DUCT OASPL'S AT 152.5-METER (500-FT) SIDELINE

[Hamilton standard 1.2 PR prop-fan (QF-9); 100 percent speed; takeoff blade setting; in-duct forward OASPL, 140.8; in-duct rear OASPL, 144.0.]

FREQ	SATTNF	SATTNR
50.	-19.0	-12.0
63.	-16.4	-9.4
80.	-14.2	-7.3
100.	-12.4	-5.6
125.	-10.6	-4.3
160.	-8.2	-3.1
200.	-4.8	-1.6
250.	-0.4	1.1
315.	4.1	4.7
400.	7.2	7.5
500.	13.6	20.1
630.	9.9	10.1
800.	9.9	10.0
1000.	9.4	14.5
1250.	9.1	9.2
1600.	8.6	15.1
2000.	8.4	15.0
2500.	7.9	14.5
3150.	6.4	13.2
4000.	6.4	13.3
5000.	1.8	8.9
6300.	-4.3	3.1
8000.	-9.5	-1.8
10000.	-19.3	-11.0

IN-DUCT OASPLF = 140.8
OASPLR = 144.0

APPENDIX B

LINER SPECIFICATION PROGRAM DESCRIPTION

Description

This appendix presents a listing of the FORTRAN IV main program and subroutines required to specify the fan acoustic liners, once the required attenuation spectra have been determined. The variables calculated are tuning frequencies, lengths of liners, backing depths, and open area ratios. In the process decisions must be made for determining numbers of splitters, passage heights, facing sheet hole diameter, and facing sheet thickness. These latter variables are constrained by practical considerations, but some freedom is possible in iterating with the former list of variables to get a "best" result. This iteration requires some judgment and experience in order to be effective.

The specific input data requirements are itemized at the beginning of the main program, and they will not be discussed in detail here.

The printed output resulting from this program is presented in tables XIX to XXIII which appear after the main program and subroutines at the end of this appendix.

Main Program and Subroutines

```
C
C       SPECIFY LINER TUNING, L/H, AND ETA.
C       ASSUME REQUIRED ATTENUATION SPECTRUM IS GIVEN.
C       ACCEPTS A GENERAL NUMBER OF TUNINGS, UP TO 5.
C       CALCULATE OPEN AREA RATIOS AND BACKING DEPTHS.
C
C       SUBROUTINES REQUIRED
C         ATTN
C         OFFOPT
C         BNDW
C         ANEWT
C         CRIT12
C         ZRTDS1
C         ARBD
C         PNDBER
C         ATSG - MODIFIED IBM SYSTEM SUBROUTINE
C         LGRTRP - LAGRANGIAN INTERPOLATION
C
C
C       DATA REQUIRED
C         XPLN(I)                       12A6
C           CONFIGURATION EXPLANATION CARD
C         PART, ETAOO                   2F10.0
C           PART = MULTIPLE OF OPTIMUM THETA DESIRED FOR OFF-OPTIMUM DESIGN
C           ETAOO = ETA BELOW WHICH USE OFF-OPTIMUM DESIGN CONSIDERATIONS.
```

```
C         NFSWCH, NLINER                   2I3
C           NFSWCH... IF ZERO, TUNE FREQUENCIES ARE EXTERNALLY SPECIFIED
C               IF NON-ZERO, FREQUENCIES ARE CALCULATED BY PROGRAM.
C           NLINER = NUMBER OF LINER TUNINGS DESIRED
C         AM, T                            2F10.0
C           AM = DUCT MACH NUMBER
C           T = TEMPERATURE IN DUCT, DEGREES R.
C         FP(I)                            5F10.0
C           EACH VALUE OF TUNING GUESSED FOR ITERATION
C         BLOH(I)                          5F10.0
C           EACH VALUE OF L OVER H GUESSED FOR EACH TUNING
C         H(I)                             5F10.0
C           DUCT HEIGHTS FOR EACH TUNING, IN.
C
C ****************************
C
C       NOTE THAT YOU CAN USE PUNCHED OUTPUT FROM THE NOISE ESTIMATE
C       PROGRAM FOR DATA BETWEEN ASTERISKS, OR GENERATE THESE DATA INDEPENDENTLY
C
C         ISTART, ISTOP                    2I3
C           ISTART = FIRST NON-ZERO 1/3 OCTAVE BAND IN ATTENUATION GOAL SPECTRUM
C           ISTOP = LAST NON-ZERO 1/3 OCTAVE BAND IN ATTENUATION GOAL SPECTRUM
C         GOAL(I)                          8F10.0
C           GOAL = 1/3 OCTAVE SPECTRUM OF GOAL ATTENUATION.
C         NF                                I3
C           NUMBER OF 1/3 OCTAVE BANDS IN SPECTRUM
C           IF ZERO, USED AS SWITCH, DO NOT READ SPL, SLJET, COND
C         SPL(I)                           8F10.0
C           1/3 OCTAVE SPECTRUM OF NOISE GENERATION, FOR PNL CALCULATION
C         SLJET(I)                         8F10.0
C           1/3 OCTAVE SPECTRUM OF JET NOISE, FLOOR FOR NOISE ATTN, FOR PNL CALC
C         COND(I)                          12A6
C           EXPLAINS LOCATION OF ABOVE SPECTRA
C         OASPL                            F10.0
C           OASPL = DUCT OASPL, DB
C           IF OASPL IS ZERO, IT ACTS AS A SWITCH, NO FURTHER READING AND NO
C           BACKING DEPTHS OR OPEN AREAS ARE CALCULATED.
C
C ****************************
C
C         PS                               F10.0
C           PS = DUCT STATIC PRESSURE, PSI
C         THA(I)                           5F10.0
C           THA(1) = FACE PLATE THICKNESS FOR FIRST TUNING, IN.
C           ETC
C         DA(I)                            5F10.0
C           DA(1) = HOLE DIAMETER FOR FIRST TUNING, IN.
C           ETC.
C
      COMMON /FREQ/ F(27)
      COMMON /PAR/ PART,ETAOO
      COMMON /PESANT/ PS,AM,T,OASPL,TH,D
      COMMON /FLOBY/ NBYSW
      DIMENSION DDB(27),GOAL(27),FU(27)
      DIMENSION XPLN(15)
      DIMENSION DIFFE(5),ET(5),DIFFL(5),BLOH(5),DDBN(5,27)
      DIMENSION FP(5),H(5),ETG(5),FPG(5),BLOHG(5),BL(5),HG(5)
      DIMENSION THETA(5),CHI(5),SIGMA(5),B(5)
      DIMENSION THA(5),DA(5)
```

```
      DIMENSION SPL(27),SLJET(27),COND(15)
      DIMENSION PEAK(5),PERL(5)
      NAMELIST /NM1/ NF,FU,AM,T,C,ET,FP,BLOH,ISTART,ISTOP,GOAL,H,NFSWCH,
     1NLINER,NLIN,PART,ETA00
      NAMELIST /NM2/ AM,ET,FP,NF,DDBN,DDB,FRAC
      NAMELIST /NM3/ ITERAT,FRAC,TESTE,DIFFE,TESTL,DIFFL
      NAMELIST /NM4/ AM,T,PS,DASPL,THA,DA
      NAMELIST /NM5/ NF,SPL,SLJET
      NAMELIST /NM6/ AM,C,PART,ETA00,FRC,FP,ET,BLOH,PERL,PEAK,DDB,DDBPK,
     1DDBN
      COMPLEX FIMP,EIG
      DATA (FU(I),I=1,27) /50.,63.,80.,100.,125.,160.,200.,250.,315.,400
     1.,500.,630.,800.,1000.,1250.,1600.,2000.,2500.,3150.,4000.,5000.,6
     2300.,8000.,10000.,12500.,16000.,20000./
      TR=1.
      NBYSW=0
C
C      NBYSW IS A SWITCH FOR CONTROL OF FLOW BY EFFECT IN IMPEDANCE MODEL
C      CALCULATION
C        = 0 USE ADDITIVE
C        = 1 USE MULTIPLICATIVE
C
 6    CONTINUE
      NF=24
      NFO=NF
      DO 1 I=1,27
 1    F(I)=FU(I)
 1000 CONTINUE
      READ (5,100) (XPLN(I),I=1,12)
 100  FORMAT (12A6)
      WRITE (6,999)
      WRITE (6,7)
 7    FORMAT (60X,10HINPUT DATA///)
      WRITE (6,1005) (XPLN(I),I=1,12)
 1005 FORMAT (35X,12A6//)
      READ (5,102) PART, ETA00
 102  FORMAT (2F10.0)
      WRITE (6,1020) PART,ETA00
 1020 FORMAT (35X,2F10.2//)
      FRC=1./PART
      READ (5,101) NFSWCH, NLINER
 101  FORMAT (2I3)
      WRITE (6,1010) NFSWCH,NLINER
 1010 FORMAT (35X,2I3//)
      NLIN=NLINER
      READ (5,2) AM,T
 2    FORMAT (2F10.0)
      WRITE (6,200) AM,T
 200  FORMAT (35X,F10.2,F10.1//)
      C=49.02*SQRT(T)
      READ (5,3) (FP(I),I=1,NLIN)
 3    FORMAT (8F10.0)
      WRITE (6,300) (FP(I),I=1,NLIN)
 300  FORMAT (35X,5F10.0)
      READ (5,3) (BLOH(I),I=1,NLIN)
      WRITE (6,301) (BLOH(I),I=1,NLIN)
 301  FORMAT (1H0,34X,5F10.1)
      READ (5,3) (H(I),I=1,NLIN)
      WRITE (6,302) (H(I),I=1,NLIN)
 302  FORMAT (1H0,34X,5F10.2)
      READ (5,4) ISTART,ISTOP
```

```
 4    FORMAT (2I3)
      WRITE (6,1011) ISTART,ISTOP
      READ (5,5) (GOAL(I),I=ISTART,ISTOP)
 5    FORMAT (8F10.0)
      WRITE (6,500) (GOAL(I),I=ISTART,ISTOP)
 500  FORMAT (1H0,34X,8F10.1)
      READ (5,5000) NF
 5000 FORMAT (I3)
      WRITE (6,1011) NF
 1011 FORMAT (1H0,34X,2I3)
      JUMP=NF
      IF (NF .EQ. 0) GO TO 5002
      READ (5,5)(SPL(I),I=1,NF)
      READ (5,5)(SLJET(I),I=1,NF)
      WRITE (6,500) (SPL(I),I=1,NF)
      WRITE (6,500) (SLJET(I),I=1,NF)
      READ (5,5001)(COND(I),I=1,12)
      WRITE (6,1012)
 1012 FORMAT (/)
      WRITE (6,1005) (COND(I),I=1,12)
 5001 FORMAT (12A6)
 5002 CONTINUE
      IF (NF .EQ. 0) NF=NFO
      READ (5,5003) OASPL
 5003 FORMAT (F10.0)
      WRITE (6,5004) OASPL
 5004 FORMAT (35X,F10.1//)
      IF (OASPL .LE. 0.01) GO TO 501
      READ (5,5003) PS
      WRITE (6,5004) PS
      READ (5,3) (THA(I),I=1,NLIN)
      READ (5,3) (DA(I),I=1,NLIN)
      WRITE (6,5005) (THA(I),I=1,NLIN)
 5005 FORMAT (35X,5F10.3)
      WRITE (6,5006) (DA(I),I=1,NLIN)
 5006 FORMAT (1H0,34X,5F10.3)
C
C      END OF INPUT DATA READING
C
 501  CONTINUE
      DET=0.
      DLOH=0.
      DO 1002 I=1,NLIN
      DO 1001 IFQ=1,NF
 1001 DDBN(I,IFQ)=0.
      DIFFE(I)=0.
      DIFFL(I)=0.
      ET(I)=H(I)*FP(I)/(C*12.)
      HG(I)=H(I)
      FPG(I)=FP(I)
      BLOHG(I)=BLOH(I)
      BL(I)=H(I)*BLOH(I)
      DET=DET+0.003*ET(I)
      DLOH=DLOH+0.003*BLOH(I)
 1002 CONTINUE
      ITERAT=0
      ITEST=0
 10   INCR=0
      IF (NFSWCH. EQ. 0) GO TO 39
      GO TO 29
 11   CONTINUE
      IF (NFSWCH. NE. 0) GO TO 12
      DO 110 J=1,NLIN
      FP(J)=FPG(J)
```

```
 110  ET(J)=H(J)*FP(J)/(12.*C)
 12   CONTINUE
      DO 122 J=1,NLIN
      TR=1.
      CALL ATTN(AM,ET(J),DDBOL)
      DDBPK=DDBOL*BLOH(J)
      IF (ET(J) .LT. ETA00 .AND. ET(J) .GT. 0.01) TR=PART
      IF (TR .EQ. 1.) GO TO 115
      CALL OFFOPT (ET(J),TR,DDBPK,DDBPKO)
      DDBPK=DDBPKO
 115  CONTINUE
      PERL(J)=DDBOL
      PEAK(J)=DDBPK
      CALL BNDW (DDBPK,ET(J),FP(J),NF,TR,DDB)
C
C      NOTE THAT DDB IS USED HERE FOR TEMPORARY STORAGE.  IT IS ALSO USED
C      BELOW FOR PRINTOUT.
C
      DO 121 IFQ=1,NF
 121  DDBN(J,IFQ)=DDB(IFQ)
 122  CONTINUE
      IF (ITEST .GT. 0) GO TO 60
C
C      ITEST IS A DUMMY VARIABLE. WHEN IT IS .GT. 0 THE CALCULATION IS
C      COMPLETE AND FINAL PRINTOUT IS PERFORMED BY THE GO TO STATEMENT.
C      ITEST IS SET .GT. 0 BELOW.
C
      SUMDSQ=0
      DO 21 IFQ=ISTART,ISTOP
      TOTL=0.
      DO 20 J=1,NLIN
 20   TOTL=TOTL+DDBN(J,IFQ)
      DEV=GOAL(IFQ)-TOTL
      DEVSQ=DEV*DEV*GOAL(IFQ)
      DEVSQ=DEV*DEV
 21   SUMDSQ=SUMDSQ+DEVSQ
      IF (LNGT-1) 31,41,41
C
C      *** NOTE THAT WHEN ANY ONE OF THE LOOPS BELOW        ***
C      *** IS FIRST REACHED THE NEEDED CALCULATIONS FOR     ***
C      *** THE DIFFERENCE SCHEME HAVE ALREADY BEEN          ***
C      *** MADE AT THE CENTRAL POINT.                       ***
C
C
C      ETA LOOP
C
 29   LNGT=0
      I=0
 30   I=I+1
      INCR=0
      GO TO 11
 31   INCR=INCR+1
      IF (INCR .EQ. 1) ETSAV=ET(I)
      GO TO (310,311,34), INCR
 310  G=SUMDSQ
      ET(I)=ETSAV-DET
      GO TO 312
 311  GM1=SUMDSQ
      ET(I)=ETSAV+DET
 312  FP(I)=ET(I)*C*12./H(I)
      GO TO 11
 34   GP1=SUMDSQ
      CALL ANEWT (ETSAV,DET,GM1,G,GP1,ETNEW)
      IF (ETNEW .LT. 0.) ETNEW=ABS(ETNEW)
```

```
      DIFFE(I)=ABS(ETSAV-ETNEW)
      ET(I)=ETNEW
      FP(I)=ETNEW*C*12./H(I)
      INCR=0
      IF (I .LT. NLIN) GO TO 30
C
C      LOH LOOP
C
 39   LNGT=1
      I=0
 40   I=I+1
      INCR=0
      GO TO 11
 41   INCR=INCR+1
      IF (INCR .EQ. 1) SAVLOH=BLOH(I)
      GO TO (410,411,412), INCR
 410  G=SUMDSQ
      BLOH(I)=SAVLOH-DLOH
      GO TO 11
 411  GM1=SUMDSQ
      BLOH(I)=SAVLOH+DLOH
      GO TO 11
 412  GP1=SUMDSQ
      CALL ANEWT (SAVLOH,DLOH,GM1,G,GP1,BLOHN)
      IF (BLOHN .LT. 0.) BLOHN=ABS(BLOHN)
      DIFFL(I)=ABS(SAVLOH-BLOHN)
      IF (SAVLOH .LE. 0.1) DIFFL(I)=0.
      BLOH(I)=BLOHN
      BL(I)=BLOHN*H(I)
      INCR=0
      IF (I .LT. NLIN) GO TO 40
 540  CONTINUE
      ITERAT=ITERAT+1
      IF (ITERAT .EQ. 10) GO TO 61
      IF (ITERAT .EQ. 20) GO TO 61
      IF (ITERAT .EQ. 30) GO TO 61
      IF (ITERAT .EQ. 50) GO TO 61
      IF (ITERAT .EQ. 100) GO TO 61
      IF (ITERAT .EQ. 200) GO TO 61
 55   CONTINUE
C
C
      FRAC=0.01
      FRAC=0.05
      FRAC=0.02
      DO 56 J=1,NLIN
      TESTE=FRAC*ET(J)
      TESTL=FRAC*BLOH(J)
C
C      IF VARIABLES ARE NOT SUFFICIENTLY CLOSE TO RESULT OF PREVIOUS ITERATION,
C      REPEAT THE ITERATION.
C
      IF (DIFFE(J) .GT. TESTE) GO TO 10
      IF (DIFFL(J) .GT. TESTL) GO TO 10
 56   CONTINUE
 58   ITEST=1
      GO TO 12
 60   CONTINUE
 61   DO 65 IFQ=1,NF
      DDB(IFQ)=0
      DO 65 J=1,NLIN
 65   DDB(IFQ)=DDB(IFQ)+DDBN(J,IFQ)
      WRITE (6,999)
```

```
  999   FORMAT (1H1)
        WRITE (6,71)
  71    FORMAT (55X,23HLINER DESIGN PARAMETERS//)
        WRITE (6,68) (XPLN(I),I=1,12)
  68    FORMAT (30X,12A6//)
        WRITE (6,710)
  710   FORMAT (60X,5HINPUT//)
        WRITE (6,711)
  711   FORMAT (45X,40H   LINER     H(INCHES)     FP          L/H//)
        DO 712 J=1,NLIN
  712   WRITE (6,713) J,HG(J),FPG(J),BLOHG(J)
  713   FORMAT (49X,I2,4X,F10.2,F10.0,F10.1)
        WRITE (6,998)
  998   FORMAT (1H0)
        WRITE (6,74)
  74    FORMAT (60X,18HCALCULATED RESULTS//)
        BLT=0.
        DO 740 J=1,NLIN
        BL(J)=H(J)*BLOH(J)
  740   BLT=BLT+BL(J)
        WRITE (6,741)
  741   FORMAT (38X,5HLINER,8X,3HL/H,7X,2HFP,4X,9HL(INCHES),2X,9HH(INCHES)
       1,4X,3HETA//)
        DO 742 J=1,NLIN
  742   WRITE (6,743) J,BLOH(J),FP(J),BL(J),H(J),ET(J)
  743   FORMAT (40X,I2,3X,F10.2,F10.0,F10.1,F10.2,F10.3)
        WRITE (6,998)
        WRITE (6,744) BLT
  744   FORMAT (50X,24HTOTAL LENGTH (INCHES) = ,F10.1)
        WRITE (6,998)
        NWHICH=0
        DO 7430 J=1,NLIN
        J=J
        IF (ET(J) .LE. ETAOO) NWHICH=J
        IF (NWHICH .NE. J) GO TO 7430
        WRITE (6,7431) NWHICH
  7430  CONTINUE
  7431  FORMAT (54X,5HLINER,I2,15H IS OFF-OPTIMUM)
        IF (NWHICH .EQ. 0) GO TO 7439
        WRITE (6,7432) PART
  7432  FORMAT (54X,9HTHETA IS ,F4.1,20H TIMES OPTIMUM THETA//)
  7439  CONTINUE
        WRITE (6,75)
  75    FORMAT (55X,19HSPECTRAL COMPARISON//)
        WRITE (6,76)
  76    FORMAT (56X,24HFREQ       GOAL        DDB//)
        DO 77 IFQ = ISTART, ISTOP
  77    WRITE (6,78) F(IFQ),GOAL(IFQ),DDB(IFQ)
  78    FORMAT (50X,F10.0,2F10.1)
        WRITE (6,79)
  79    FORMAT (1H0///)
        WRITE (6,80) ITERAT
  80    FORMAT (50X,20HNUMBER ITERATIONS = ,I4)
        IF (ITEST .NE. 1) GO TO 55
C
C        CALCULATE PNL FOR HARD AND SOFT CONFIGUATIONS
C
        IF (JUMP .EQ. 0) GO TO 83
        CALL PNDBER (1,NF,SPL,PNDB1,PNDB2)
        PNLHRD=PNDB1
        DO 81 IFQ=1,NF
        SPL(IFQ)=SPL(IFQ)-DDB(IFQ)
        IF (SPL(IFQ) .LT. SLJET(IFQ)) SPL(IFQ)=SLJET(IFQ)
```

```
81    CONTINUE
      CALL PNDBER (1,NF,SPL,PNDB1,PNDB2)
      PNLSFT=PNDB1
      WRITE (6,999)
      WRITE (6,9999)
9999  FORMAT (1H0//////////)
      WRITE (6,810)
810   FORMAT (49X,32HESTIMATED PERCEIVED NOISE LEVELS//)
      WRITE (6,68) (XPLN(I),I=1,12)
      WRITE (6,68) (COND(I),I=1,12)
      WRITE (6,82) PNLHRD,PNLSFT
82    FORMAT (51X,16HHARD WALL PNL = ,F10.1/
     151X,16HSOFT WALL PNL = ,F10.1//
     248X,33HJET NOISE FLOOR EFFECT CONSIDERED)
83    CONTINUE
C
C      NOW SPECIFY BACKING DEPTHS, OPEN AREAS, ETC.
C
      IF (OASPL .LE. 0.01) GO TO 95
      DO 90 J=1,NLIN
      CALL CRIT12(ET(J),AM,FIMP,RO,TO,EIG)
      FIMP=FIMP*ET(J)
      THETA(J)=REAL(FIMP)
      IF (ET(J) .LE. ETA00) THETA(J)=PART*THETA(J)
      CHI(J)=AIMAG (FIMP)
      TH=THA(J)
      D=DA(J)
      CALL ARBD (THETA(J),CHI(J),FP(J),SIGMA(J),B(J))
90    CONTINUE
      WRITE (6,999)
      WRITE (6,900)
900   FORMAT (46X,37HSPECIFICATIONS OF LINER WALL GEOMETRY///)
      WRITE (6,68) (XPLN(I),I=1,12)
      WRITE (6,91)
91    FORMAT (38X,5HLINER,8X,2HFP,7X,5HTHETA,6X,3HCHI,3X,10HSIGMA(PCT),2
     1X,6HB(IN.)//)
      DO 92 J=1,NLIN
92    WRITE (6,93) J,FP(J),THETA(J),CHI(J),SIGMA(J),B(J)
93    FORMAT (39X,I2,4X,F10.0,2F10.3,F10.1,F10.3)
      WRITE (6,998)
      WRITE (6,94)
94    FORMAT (57X,14HFOR INPUT DATA//)
      WRITE (6,940) OASPL,PS
940   FORMAT (52X,16HOASPL IN-DUCT = ,F10.1/
     152X,19HPS(PSIA) IN-DUCT = ,F10.1//)
      WRITE (6,941) (THA(I),I=1,NLINER)
941   FORMAT (45X,9HTH(IN) = ,5F10.3//)
      WRITE (6,942) (DA(I),I=1,NLINER)
942   FORMAT (45X,8HD(IN) = ,5F10.3)
95    CONTINUE
      NOCHNG=1
      IF (NOCHNG .EQ. 1) GO TO 1000
      STOP
      END
```

```
      SUBROUTINE ANEWT (X,DX,GM1,G,GP1,XNEW)
C
C      CALCULATE NEW GUESSED VALUE FOR ROOT, I.E. X, FOR AN EQUATION
C        Y = F(X), FIND X SUCH THAT Y IS ZERO.
C        IN PRESENT CASE F(X) IS THE FIRST DERIVATIVE OF G WRT X.
C        APPLICATION IS FOR FINDING OPTIMUM (MAX OR MIN).
C        METHOD USED IS NEWTON ITERATION.
C          X(N+1)=X(N)-F(X(N))/(DF(X(N))/DX)
C
C
C      THE DERIVATIVES ARE FOUND BY CENTRAL DIFFERENCE SCHEME.
C      THUS THE CALLING PROGRAM MUST PROVIDE FUNCTIONAL VALUES AT THE POINT
C      WHERE THE DERIVATIVE IS DESIRED, AS WELL AS AT A STEP ON EITHER SIDE
C      OF THE POINT.
C        THESE VALUES ARE STORED IN GM1, G, GP1.
C       X IS THE CENTRAL POINT.
C        DX IS THE STEP SIZE.
C        XNEW IS THE CALCULATED NEW VALUE IN THE ITERATION FOR THE ROOT.
C
      DGDX=(GP1-GM1)/(2.*DX)
      DGDX2=(GP1-2.*G+GM1)/(DX*DX)
      F=DGDX
      DFDX=DGDX2
      XNEW=X-F/DFDX
      RETURN
      END
```

```
      SUBROUTINE ATTN (AM,ETA,DDBOL)
C
C      CALCULATE PEAK ATTENUATION FOR A LINER, GIVEN ETA AND MACH NUMBER.
C      NOTE THAT THIS IS VERSION 3 OF THIS PROGRAM
C      MACH NUMBER EFFECTS ARE HEREIN HANDLED BY INTERPOLATING
C      BETWEEN THE CURVES AT FIXED MACH NUMBERS.
C
C      ARGUMENTS INPUT
C        AM = FLOW-BY MACH NUMBER
C        ETA = LINER CHARACTERISTIC PARAMETER
C      AGRUMENT OUT
C        DDBOL = PEAK ATTENUATION/(L/H), FOR OPTIMIZED RESISTANCE,
C        LEAST ATTENUATED MODE RECTANGULAR DUCT.
C
      DIMENSION D(6,4),C(4),B(5)
      DIMENSION AMSTOR(10),WORK(10),ARG(10),VAL(10)
      DIMENSION DDB(10)
      DATA (B(K),K=1,5) /.41792,.57188,.64086,.23905,14.167/
      DATA ((D(IM,J),J=1,4),IM=1,6) /1.5475,45.497,18.811,2.4012,1.1661,
     110.937,9.3986,1.1438,0.,0.,0.,0.,-2.0987,30.741,12.255,2.4699,-3.5
     2123,49.095,13.861,3.5251,-4.1881,48.918,14.121,3.4267/
      DATA (AMSTOR(IM),IM=1,6) /-.4,-.2,0.,.25,.4,.5/
C
C      CALCULATE MACH=0 PEAK ATTENUATION.
C
```

```
      EXP1=(ALOG(ETA)-ALOG(B(2)))/B(3)
      EXP2=-0.5*EXP1*EXP1
      TRM1=B(1)*EXP(EXP2)
      TRM2=EXP(TRM1)
      COEFF=B(5)/(B(4)+ETA)
      DDBNRM=COEFF*TRM2
      IF (ETA .GE. 2.) GO TO 50
      IDENT=0
      ITEST=0
      DO 25 IM=1,6
      IF (AM .EQ. AMSTOR(IM)) GO TO 23
      GO TO 25
 23   ITEST=1
      IDENT=IM
 25   CONTINUE
C
C      SET UP CURVES OF DELTA DB PK AT MESH POINT MACH NUMBERS.
C
C      LOOP ON IDUM IS FOR MACH NUMBER.
C      THE J INDEX IS FOR THE PARAMETERS IN THE FIT OF DELTA VERSUS ETA,
C      AT THE SELECTED MACH NUMBER.
C
      DO 31 IDUM=1,6
      IF (ITEST .EQ. 1) GO TO 26
      IM=IDUM
      GO TO 27
 26   IM=IDENT
 27   CONTINUE
      IF (IM .EQ. 3) GO TO 29
      EXPN=D(IM,2)/(D(IM,4)+ETA)-D(IM,3)
      DEL=D(IM,1)*ETA**EXPN
      GO TO 30
 29   DEL=0.
 30   DDB(IM)=DDBNRM+DEL
      IF (ITEST .EQ. 1) GO TO 51
 31   CONTINUE
C
C      INTERPOLATE ON MACH NUMBER TO THE DESIRED VALUE.
C
      NDIM=3
      ICOL=1
      IROW=6
      CALL ATSG (AM,AMSTOR,DDB,WORK,IROW,ICOL,ARG,VAL,NDIM)
      CALL LGRTRP (ARG,VAL,NDIM,AM,DDBOL)
      GO TO 52
 50   DEL=0.
 51   DDBOL=DDBNRM+DEL
 52   CONTINUE
      DDBOL=DDBOL*0.4
      RETURN
      END
```

```
      SUBROUTINE PNDBER (I1,I2,DB,PNDB1,PNDB2)
C
C      THIS SUBROUTINE COMPUTES THE PNL FOR SPECTRUM DB, WHICH IS AN ARRAY WITH
C      THE INDEX I CORRESPONDING TO THE NUMBERS OF THE THIRD OCTAVE BANDS.
C
C      ARGUMENTS
C        I1 = FIRST BAND TO BE CONSIDERED IN PNDB CALCULATION NORMALLY 1
C        I2 = LAST BAND
C        DB = ARRAY CONTAINING THE SPECTRUM WHOSE PNL IS TO BE CALCULATED
C        PNDB1 = PNL CALCULATED BY SMOOTHED CURVE FIT OF THE TABULAR
C          DATA
C        PNDB2 = PNL CALCULATED USING TABULAR DATA.
C
      DIMENSION DB1(9),DB10(9),DB64(15),DB50(10),DB(27)
      DATA (DB1(I),I=1,9)/63.6,59.7,56.2,53.,50.6,48.,45.6,44.5,43./
      DATA (DB10(I),I=1,9)/87.,85.,83.1,80.,79.2,78.,76.,75.,74./
      DATA (DB64(I),I=1,15)/112.,111.,109.,107.,106.,105.,103.,102.,101.
     1,100.,100.,100.,100.,100.,98./
      DATA (DB50(I),I=1,10)/91.,89.,87.,86.,86.,87.,88.,91.,94.,97./
      SUMN1=0.0
      SUMN2=0.0
      FMAX1=0.0
      FMAX2=0.0
      DO 50 I=I1,I2
      IF (I .GT. 15) GO TO 30
      EX=0.030103*(DB(I)-DB64(I))
      FN1=64.0*10.0**EX
      FN2=FN1
      IF (FN1 .GT. 15. .OR. I .GT. 9) GO TO 40
      EX=(DB(I)-DB1(I))/(DB10(I)-DB1(I))
      FNLOW=10.0**EX
      IF (FNLOW .LT. FN1) FN1=FNLOW
      FN2=FN1
      GO TO 40
   30 J=I-15
      DBC=DB50(J)
      EX=0.030103*(DB(I)-DBC)
      FN1=50.0*10.0**EX
      IF (DB(I) .GE. DBC) GO TO 35
      X=(DBC-DB(I))**3
      FN1=FN1*(1.0+0.0279*X/(1.0+0.6*X))
      FN2=FN1
      GO TO 40
   35 X=DB(I)-DBC
      ARG=0.2*3.1415927*X
      FS=SIN(ARG)
      COR=FS
      IF (X .GT. 10.0) GO TO 37
      COR=(3.5-0.275*X)*FS
      IF (X .LT. 3.0) COR=COR+0.6*X*(3.0-X)
   37 FN2=FN1*(1.0+0.01*COR)
   40 SUMN1=SUMN1+FN1
      SUMN2=SUMN2+FN2
      IF (FN1 .GT. FMAX1) FMAX1=FN1
      IF (FN2 .GT. FMAX2) FMAX2=FN2
   50 CONTINUE
      F1=0.85*FMAX1+0.15*SUMN1
      F2=0.85*FMAX2+0.15*SUMN2
      PNDB1=10.0*(4.0+ALOG10(F1)/0.30103)
      PNDB2=10.0*(4.0+ALOG10(F2)/0.30103)
      RETURN
      END
```

```
      SUBROUTINE BNDW (DDBPK,ETA,FP,NF,TR,DDB)
C
C      CALCULATE ATTENUATION SPECTRUM FOR LINER WITH SPECIFIED PEAK
C      ATTENUATION, ETA, FREQUENCY OF PEAK, AND RESISTANCE RATIO.
C
C      ARGUMENTS IN
C        DDBPK - LINER PEAK ATTENUATION. MUST BE ADJUSTED EXTERNALLY IF
C                LINER IS OFF-OPTIMUM.
C        ETA - LINER CHARACTERISTIC PARAMETER, AT PEAK FREQUENCY.
C        FP - LINER PEAK FREQUENCY
C        NF - NUMBER OF THIRD OCTAVE FREQUENCIES FOR CALCULATING SPECTRUM
C        TR - RATIO OF RESISTANCE/OPTIMAL RESISTANCE.
C      ARGUMENT OUT
C        DDB I) - ARRAY CONTAINING THIRD OCTAVE ATTENUATION SPECTRUM
C
      COMMON /FREQ/ F(27)
      DIMENSION ET(5),THR1(5,5),A1(5,4),B1(5,4),Y1(5)
      DIMENSION WORK(5),ARG(5),VAL(5)
      DIMENSION A2OPT(3),B2OPT(3),THR2(4),A2(3),B2(3),BPWL(2),DDB(27)
      DATA (ET(I),I=1,5) /.1,.4,1.,2.,10./
      DATA ((THR1(I,J),J=1,5),I=1,5) /.1,.69,1.,3.05,10., .1,.6,1.,3.7,1
     10., .1,.55,1.,2.8,10., .1,.57,1.,2.42,10., .1,.484,1.,2.25,10./
      DATA ((A1(I,J),J=1,4),I=1,5) /-.051,-.036,-.036,.084, -.119,-.086,
     1-.086,.262, -.276,-.215,-.215,.105, -.416,-.314,-.314,-.037, -.553
     2, -.444,-.444,-.143/
      DATA ((B1(I,J),J=1,4),I=1,5) /0.,0.089,-.103,-.352, 0.,.149,-.348,
     1-.961, 0.,.235,-.417,-1.132, 0.,.415,-.471,-1.192, 0.,.346,-.401,-
     21.255/
      DATA (A2OPT(I),I=1,2) /.316,.328/
      DATA (B2OPT(I),I=1,2) /.083,.025/
      DATA (THR2(J),J=1,4) /.1,1.,1.9,10./
      DATA (A2(J),J=1,3) /.312,.312,.236/
      DATA (B2(J),J=1,3) /0.,.833,1.107/
      DATA NETA,NSEG1,NSEG2 /5,4,3/
C
C      CHECK TO SEE IF ETA EQUALS ONE OF THE STANDARD VALUES, FOR F1.
C
      IWHICH=0
      TOL=.005
      DO 10 I=1,NETA
      I=I
      ETLO=ET(I)*(1.-TOL)
      ETHI=ET(I)*(1.+TOL)
      IF (ETA .GE. ETLO .AND. ETA .LE. ETHI) IWHICH=I
      IF (ETA .GT. ET(NETA)) IWHICH=NETA
   10 CONTINUE
C
C      CALCULATE QUANTITIES FOR F1 AT EACH STANDARD ETA WHEN INPUT ETA IS
C      NOT A STANDARD VALUE.
C
      DO 40 I=1,NETA
      JWHICH=0
      DO 20 J=1,NSEG1
      J=J
      IF (TR .GE. THR1(I,J) .AND. TR .LE. THR1(I,J+1)) JWHICH=J
   20 CONTINUE
      IF (JWHICH .GT. 0) GO TO 30
      IF (TR .LT. THR1(I,1)) JWHICH=1
      IF (TR .GT. THR1(I,NSEG1)) JWHICH=NSEG1
   30 Y1(I)=A1(I,JWHICH)+B1(I,JWHICH)*ALOG10(TR)
   40 CONTINUE
```

```
      IF (IWHICH .GT. 0) GO TO 45
C
C      INTERPOLATE THE VALUE FOR NON-STANDARD ETA.
C
      NDIM=3
      CALL ATSG (ETA,ET,Y1,WORK,NETA,1,ARG,VAL,NDIM)
      CALL LGRTRP (ARG,VAL,NDIM,ETA,Y1ETA)
      GO TO 46
 45   Y1ETA=Y1(IWHICH)
 46   CONTINUE
      F1OFP=10.**Y1ETA
C
C      NOW CALCULATE F2/FP, DO OPTIMAL CASE FIRST.
C
      IF (ETA .GT. 1.58) GO TO 60
      JWHICH=1
      GO TO 61
 60   JWHICH=2
 61   CONTINUE
      Y2OPT=A2OPT(JWHICH)+B2OPT(JWHICH)*ALOG10(ETA)
      FR2OPT=10.**Y2OPT
      IF (TR .NE. 1.) GO TO 65
      F2OFP=FR2OPT
      GO TO 85
 65   CONTINUE
      JWHICH=0
      DO 70 J=1,NSEG2
      J=J
      IF (TR .GE. THR2(J) .AND. TR .LE. THR2(J+1)) JWHICH=J
 70   CONTINUE
      IF (JWHICH .GT. 3) GO TO 80
      IF (TR .LT. THR2(1)) JWHICH=1
      IF (TR .GT. THR2(NSEG2)) JWHICH=NSEG2
 80   Y21=A2(JWHICH)+B2(JWHICH)*ALOG10(TR)
      FOFF2=10.**Y21
      F2OFP=FOFF2*(FR2OPT/2.05)
 85   CONTINUE
      F2OFP=F2OFP*1.34/2.15
C
C      CALCULATE OFF-PEAK DELTA PWLS.
C
      BPWL(1)=ALOG10(.5)/ALOG10(F1OFP)
      BPWL(2)=ALOG10(.5)/ALOG10(F2OFP)
      DO 90 I=1,NF
      J=1
      FR=F(I)/FP
      IF (FR .GT. 1.) J=2
      Y=BPWL(J)*ALOG10(FR)
      FRAC=10.**Y
 90   DDB(I)=DDBPK*FRAC
      RETURN
      END
```

```
      SUBROUTINE OFFOPT (ETA,TR,DDBPK,DDBPKO)
C
C       CALCULATE PEAK ATTENUATION OF A LINER FOR WHICH THE RATIO OF
C       RESISTANCE/OPTIMAL RESISTANCE IS NOT 1.
C
C       ARGUMENTS IN
C         ETA - VALUE OF FH/C AT FREQUENCY OF PEAK ATTENUATION
C         TR - RESISTANCE/OPTIMAL RESISTANCE, AT FREQUENCY OF PEAK ATTENUATION
C         DDBPK - PEAK ATTENUATION, OPTIMAL
C       ARGUMENT OUT
C         DDBPKO - PEAK ATTENUATION, OFF OPTIMAL
C
      DIMENSION ET(3),A(3,3),B(3,3),THR(3,4),YG(3)
      DIMENSION WORK(5),ARG(5),VAL(5)
      DATA (ET(I),I=1,3) /.1,.4,1./
      DATA ((A(I,J),J=1,3),I=1,3) /0.,0.,-.151, 0.,0.,-.116, 0.,0.,-.110
     1/
      DATA ((B(I,J),J=1,3),I=1,3) /-1.,.382,.753, -1.,.790,1.167, -1.,.8
     175,1.248/
      DATA ((THR(I,J),J=1,4), I=1,3) /.1,1.,2.55,10., .1,1.,2.03,10., .1
     1,1.,1.97,10./
      DATA NETA,NSEG /3,3/
C
C       IF RESISTANCE RATIO IS EQUAL TO OR LESS THAN 1. USE SINGLE LINE
C       FOR ALL ETA.
C
      IF (TR .GT. 1.) GO TO 20
      Y=A(1,1)+B(1,1)*ALOG10(TR)
      GO TO 60
C
C       CALCUALTE BETAS AT STANDARD ETAS
C
 20   IWHICH=0
      DO 30 I=1,NETA
      I=I
      IF (ETA .EQ. ET(I)) IWHICH=I
 30   CONTINUE
      IF (ETA .GE. ET(NETA)) IWHICH=NETA
      DO 50 I=1,NETA
      JWHICH=0
      DO 40 J=2,NSEG
      J=J
      IF (TR .GE. THR(I,J) .AND. TR .LE. THR(I,J+1)) JWHICH=J
 40   CONTINUE
      IF (TR .GT. THR(I,NSEG)) JWHICH=NSEG
 50   YG(I)=A(I,JWHICH)+B(I,JWHICH)*ALOG10(TR)
C
C       INTERPOLATE THE VALUE FOR NON-STANDARD ETA.
C
      IF (IWHICH .EQ. 0) GO TO 55
      Y=YG(IWHICH)
      GO TO 60
 55   CONTINUE
      NDIM=3
      CALL ATSG (ETA,ET,YG,WORK,NETA,1,ARG,VAL,NDIM)
      CALL LGRTRP (ARG,VAL,NDIM,ETA,Y)
      BETAO=10.**Y
      DDBPKO=DDBPK/BETAO
      RETURN
      END
```

```
C
C   CALCULATES BRANCH PCINT IMPEDANCE R. THETA. FIRST.SECOND MODE
C
      SUBROUTINE CRIT12(ETA,FMACH,FIMP,R,T,EIG)
      COMPLEX FIMP.EIG
      IF(FMACH.LT.0.0) GO TO 20
      RAT = 1.0-0.276*FMACH*(1.0+0.8*FMACH)/(ETA**2+0.8*FMACH)
      IF(ETA.LT.1.0) GO TO 10
      DT = 3.2*FMACH*(3.5-ETA)
      IF(DT.LT.0.0) DT=0.0
      GO TO 40
   10 DT = 30.0*FMACH*(ETA*(2.0-ETA)-0.7)
      GO TO 40
   20 RAT = 1.0-FMACH*(0.13-(2.75+2.5*FMACH)*ALOG10(ETA))
      IF(RAT.LT.1.0) RAT=1.0
      IF(ETA.LT.1.0) GO TO 30
      DT = 2.8*FMACH*(7.0-4.0*ETA)
      IF(DT.GT.0.0) DT=0.0
      GO TO 40
   30 DT = 40.0*FMACH*(ETA*(1.6-ETA)-0.39)
   40 R = RAT*2.39
      T = 28.0+DT
      ANG = T/57.29578
      F1 = R*COS(ANG)
      F2 = R*SIN(ANG)
      EIG = CMPLX(F1,F2)
      IASYM=0
      CALL ZRTDS1(EIG,ETA,FMACH,FIMP,IASYM)
      RETURN
      END
```

```
C
C   CALCULATES Z/(RHO*C*ETA) RECT.DUCT,DISP.CONT. BCTH WALLS SAME IMPED.
C   DUCT WALLS AT Y = -AO.+AO
C
      SUBROUTINE ZRTDS1(EIG.ETA.FMACH.FIMP.IASYM)
      COMPLEX EIG.FIMP.UNCP.S.Q.CP1
      UNCP = CMPLX(0.0,1.0)
      PI = 3.1415927
      FM1 = 1.0-FMACH**2
      CP1 = FM1*(EIG/PI/ETA)**2-1.0
      S = CSQRT(CP1)
      Q = (1.0+UNCP*FMACH*S)/FM1
      FIMP = UNCP*PI*CCOS(EIG)*Q**2/(EIG*CSIN(EIG))
      IF(IASYM.EQ.0) GO TO 10
      FIMP =-UNCP*PI*CSIN(EIG)*Q**2/(EIG*CCOS(EIG))
   10 CONTINUE
      RETURN
      END
```

```
      SUBROUTINE ARBD (THETA,CHI,FP,SIGMA,B)
C
C      CALCULATE AREA RATIO AND BACKING DEPTH FOR LINER DESIGN.
C      IMPEDANCE MODEL USES ADDITIVE FLOW-BY CORRECTION.
C      UNLESS NBYSW IS OTHER THAN ZERO, E.G. 1
C
C      ARGUMENTS
C        THETA = NORMALIZED RESISTANCE
C        CHI = NORMALIZED REACTANCE
C        FP = LINER TUNE FREQUENCY
C        SIGMA = PERCENT OPEN AREA
C        B = CAVITY BACKING DEPTH, INCHES
C      IN COMMON
C        PS = DUCT STATIC PRESSURE, PSI
C        AM = DUCT MACH NUMBER
C        T = DUCT TEMPERATURE, DEGREES RANKINE
C        OASPL = DUCT OASPL
C        TH = FACING SHEET THICKNESS, INCHES
C        D = FACING SHEET HOLE DIAMETER, INCHES
C        NBYSW = SWITCH TO TELL DESIRED IMPEDANCE MODEL TO USE.
C          IF ZERO, USE ADDITIVE FLOW-BY
C          IF NON-ZERO, USE LINEAR FLOW-BY.
C
      COMMON /PESANT/ PS,AM,T,OASPL,TH,D
      COMMON /FLOBY/ NBYSW
      NAMELIST /NA1/ PS,AM,T,OASPL,TH,D,THETA,CHI,FP,OMEGA
      NAMELIST /NA2/ RHO,C,Z
      NAMELIST /NA3/ AMU,GNU,SP
      AMSAV=AM
      AM=ABS(AM)
      OMEGA=2.*3.1415927*FP
      RHO=2.710982*PS/T
      C=49.02*SQRT(T)
      VINF=ABS(AM)*C
      AMU=(7.30248E-7)*(T**1.5)/(T+198.72)
      GNU=AMU/RHO
      PREF=2.*14.5038*144.E-10
      SP=PREF*10.**(OASPL/20.)
      BETA=(1.+TH/D)*SQRT(8.*GNU*OMEGA)/C
      ZETA=0.3*ABS(AM)
      Z=SQRT(THETA**2+CHI**2)
      GAMMA=SP*32.17/(RHO*C*C*Z)
      GAMPRM=.424*SQRT(2.)*GAMMA
      IF (NBYSW .NE. 0) GO TO 10
      FIRST=BETA+ZETA
      SECOND=FIRST*FIRST+4.*THETA*GAMPRM
      GO TO 11
 10   FIRST=BETA
      SECOND=BETA*BETA+4.*THETA*GAMMA*(1.+0.006*VINF)
 11   SIGMA=(FIRST+SQRT(SECOND))/(2.*THETA)
      DELTA=0.85*D*(1.-.7*SQRT(SIGMA))/(1.+305.*(ABS(AM))**3)
      ALE=TH+DELTA
      ARG=OMEGA*ALE/(SIGMA*C*12.)-CHI
      ARG=1./ARG
      B=ATAN(ARG)*C*12./OMEGA
      IF (B .LE. 0.) B=B+3.1415927*C*12./OMEGA
      SIGMA=SIGMA*100.
      AM=AMSAV
      RETURN
      END
```

Printed Output

The initial page of the output section is a listing of sample data in proper format for running the program. The remaining pages contain the liner design information calculated by the program, including a comparison between the goal attenuation spectrum and the predicted spectrum for the liner design. The variable names used are, as nearly as possible, consistent with the symbols in the body of the report. Obvious exceptions to this are the Greek symbols, such as η, which are not available on the computer printer are therefore spelled out, such as "ETA".

TABLE XIX. - SET OF INPUT DATA - LINER DESIGN

[Note that initial guesses must be made for tune frequency and liner lengths to begin iteration solutions.]

```
     2.00       0.70
 1  2
     0.40      519.0
     500.      2500.
      2.0        4.0
     9.70       9.70
 8 22
      1.0        4.7        7.5       20.1       10.1       10.0       14.5        9.3
     15.1       15.0       14.5       13.2       13.3        8.9        3.1
24
     69.2       70.2       70.6       70.7       70.3       69.9       70.1       71.3
     73.6       75.9       88.5       78.5       78.4       82.2       75.2       78.2
     75.4       73.0       70.7       70.9       67.4       63.5       61.4       55.0
     69.2       70.2       70.6       70.6       70.1       69.3       68.1       66.9
     65.5       64.0       62.4       60.8       59.1       57.4       55.8       53.9
     52.2       50.4       48.3       46.1       43.6       40.6       36.9       32.5
          AT         500. FEET SIDE           120. DEGREES
    144.0
     15.0
    1.500      0.020
    0.250      0.050
```

TABLE XX. - LINER DESIGN PARAMETERS

[Liner for Hamilton standard based on noise estimate, exhaust, and 90.0-PNdB goal.]

INPUT

LINER	H(INCHES)	FP	L/H
1	9.70	500.	2.0
2	9.70	2500.	4.0

CALCULATED RESULTS

LINER	L/H	FP	L(INCHES)	H(INCHES)	ETA
1	2.35	502.	22.8	9.70	0.363
2	6.24	3006.	60.6	9.70	2.176

TOTAL LENGTH (INCHES) = 83.4

LINER 1 IS OFF-OPTIMUM
THETA IS 2.0 TIMES OPTIMUM THETA

SPECTRAL COMPARISON

FREQ	GOAL	DDB
250.	1.0	5.1
315.	4.7	7.1
400.	7.5	10.1
500.	20.1	14.2
630.	10.1	12.9
800.	10.0	12.0
1000.	14.5	11.7
1250.	9.3	11.8
1600.	15.1	12.6
2000.	15.0	13.8
2500.	14.5	15.6
3150.	13.2	15.9
4000.	13.3	9.7
5000.	8.9	6.2
6300.	3.1	3.9

NUMBER ITERATIONS = 6

TABLE XXI. - ESTIMATED HARD AND SOFT

WALL PNL'S AT 152.5-METER (500-FT)

SIDELINE AND 120°

[Liner for Hamilton standard based on noise estimate, exhaust, and 90.0-PNdB goal.]

HARD WALL PNL = 100.5
SOFT WALL PNL = 89.5

JET NOISE FLOOR EFFECT CONSIDERED

TABLE XXII. - SPECIFICATIONS OF LINER WALL GEOMETRIES INCLUDING TUNING, IMPEDANCES, INPUT WALL THICKNESSES, AND HOLE DIAMETERS

[Liner for Hamilton standard based on noise estimate, exhaust, and 90.0-PNdB goal.]

LINER	FP	THETA	CHI	SIGMA(PCT)	B(IN.)
1	502.	0.595	0.191	23.7	2.779
2	3006.	1.115	-0.794	12.0	0.541

FOR INPUT DATA

CASPL IN-DUCT = 144.0
PS(PSIA) IN-DUCT = 15.0

TH(IN) =	1.500	0.020
D(IN) =	0.250	0.050

Definition of variables:

FP	Peak frequency
THETA	Specific resistance
CHI	Specific reactance
SIGMA	Face sheet percent open area
B	Cavity backing depth
TH	Face sheet thickness
D	Face sheet perforation diameter

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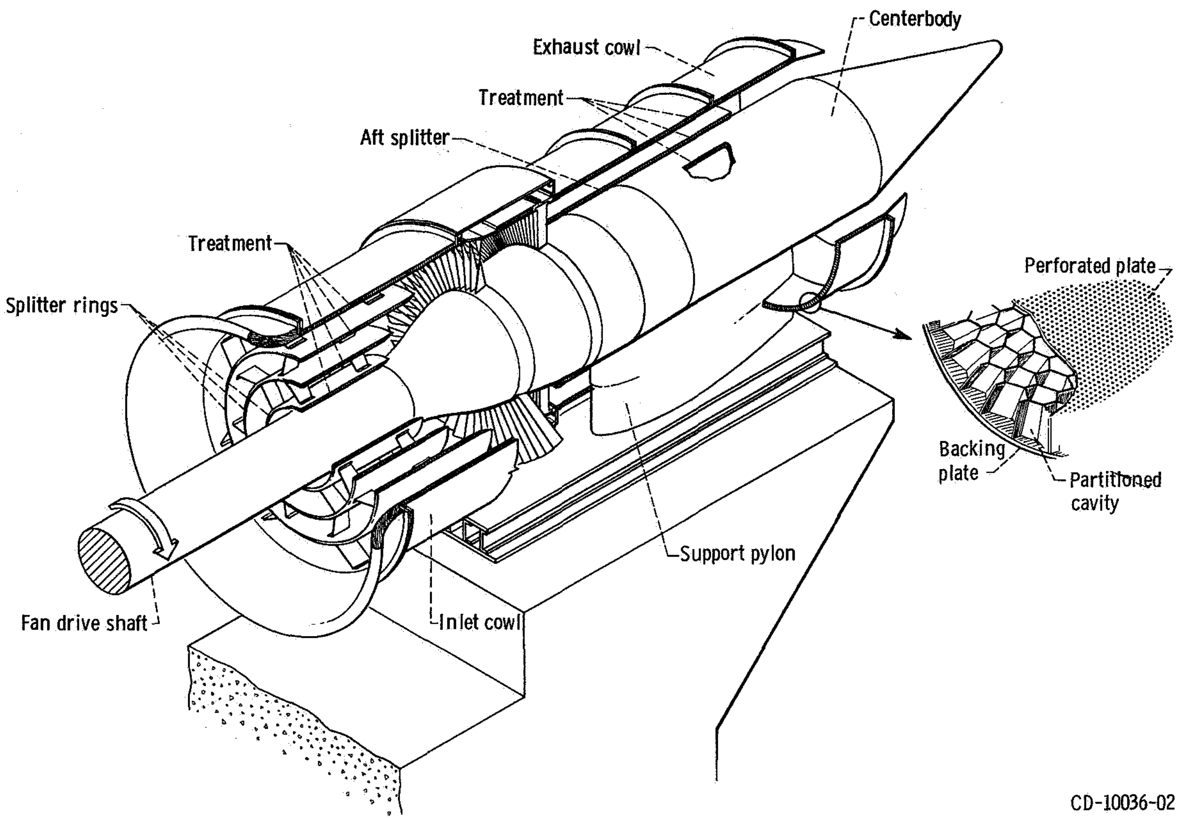


Figure 1. - Cutaway view of example fan and suppressor assembly.

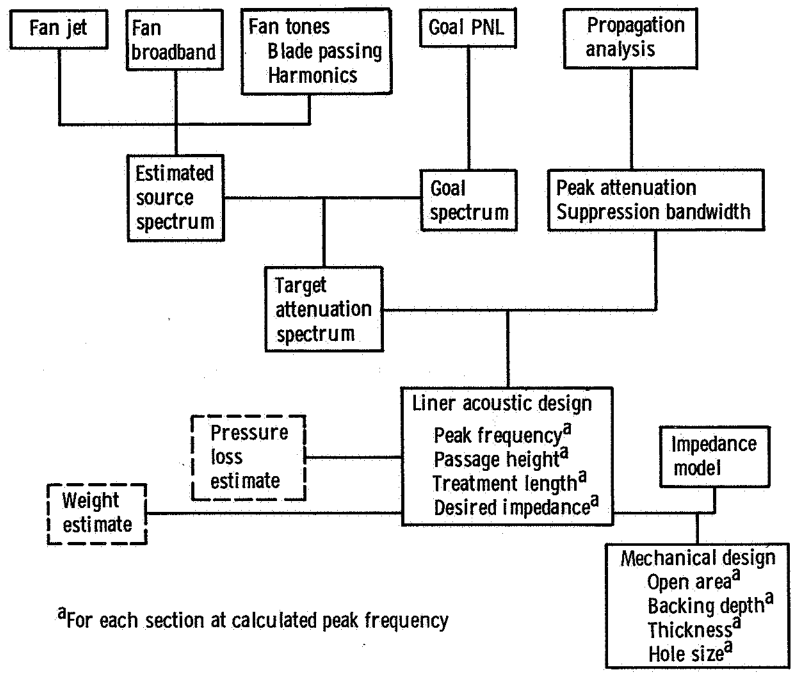


Figure 2. - Suppressor design procedure.

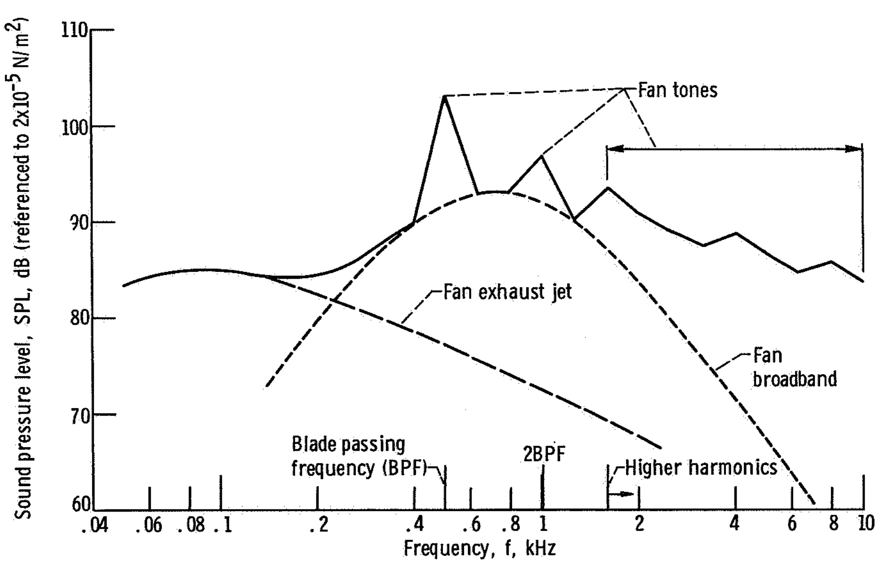


Figure 3. - Composite noise prediction spectrum for fan at 30.5-meter (100-ft) sideline, 120° from inlet direction. Aerodynamic parameters given in table I.

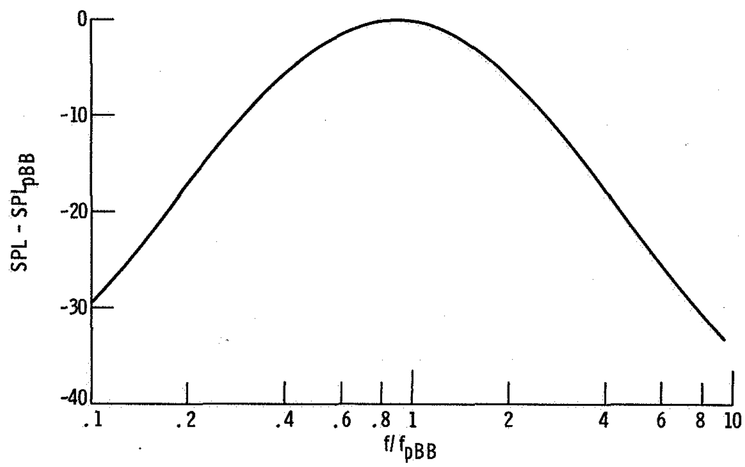


Figure 4. - Fan broadband spectral shape curve fit of data from reference 1.

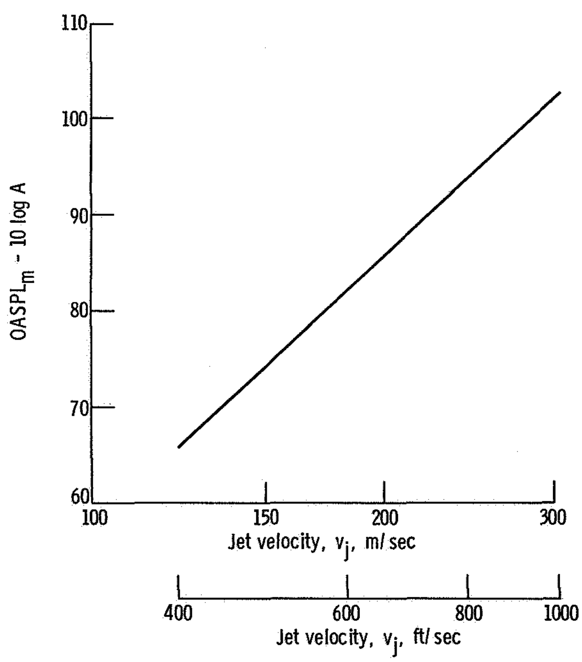


Figure 5. - Fan jet noise level at 30.5-meter (100-ft) sideline; maximum angle (A is nozzle area in sq ft).

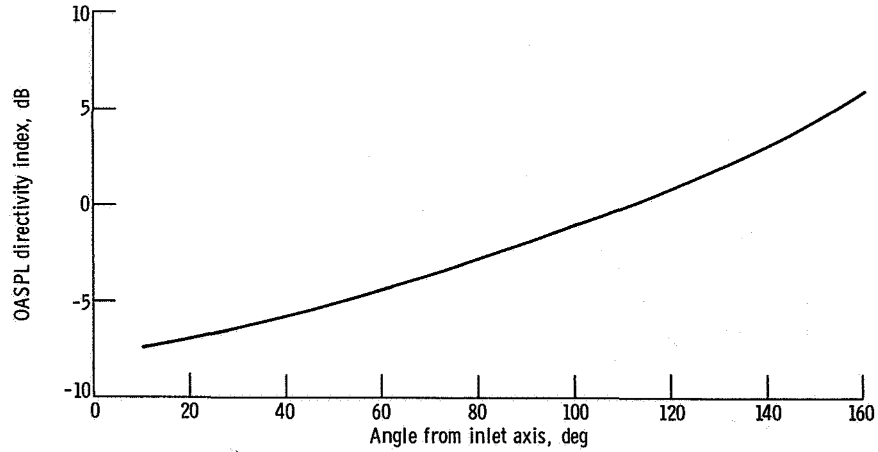


Figure 6. - Jet noise directivity index from reference 11.

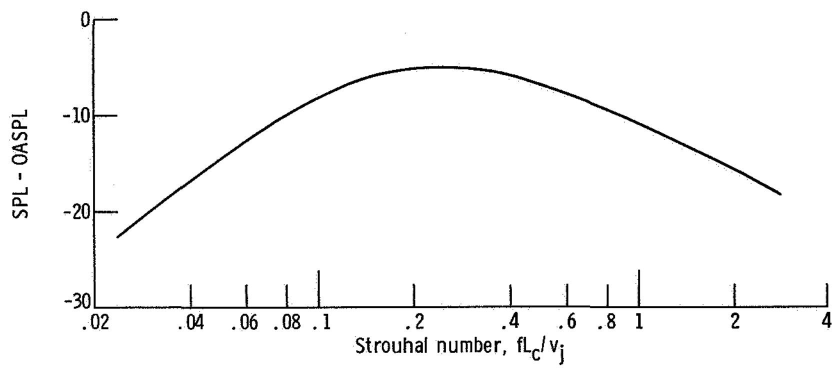


Figure 7. - Octave-band jet noise spectrum from reference 10.

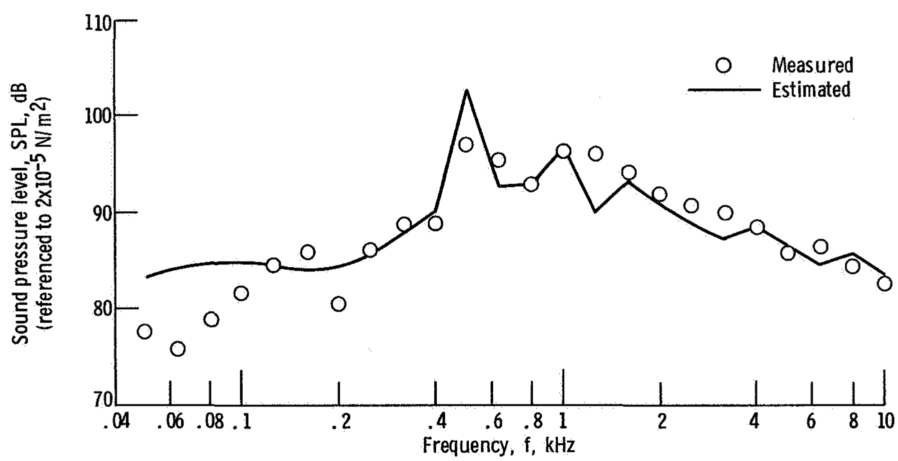


Figure 8. - Comparison of noise estimate and measured results for 1.2 pressure ratio QF-9 fan. Design configuration and speed; 30.5-meter (100-ft) sideline; 120° from inlet direction.

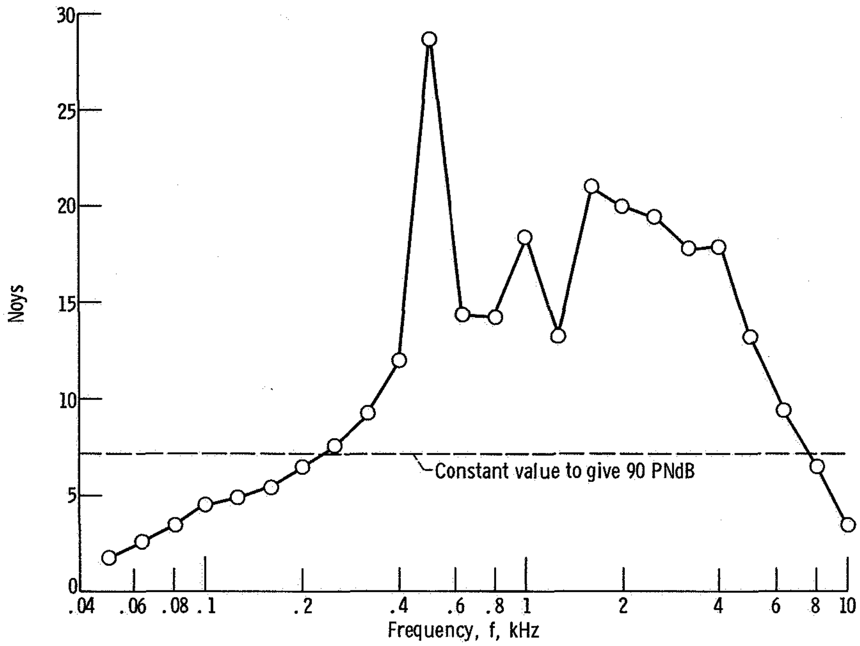


Figure 9. - Annoyance-weighted spectrum for noise estimate of figure 3 at 152.5-meter (500-ft) sideline; 120° from inlet direction.

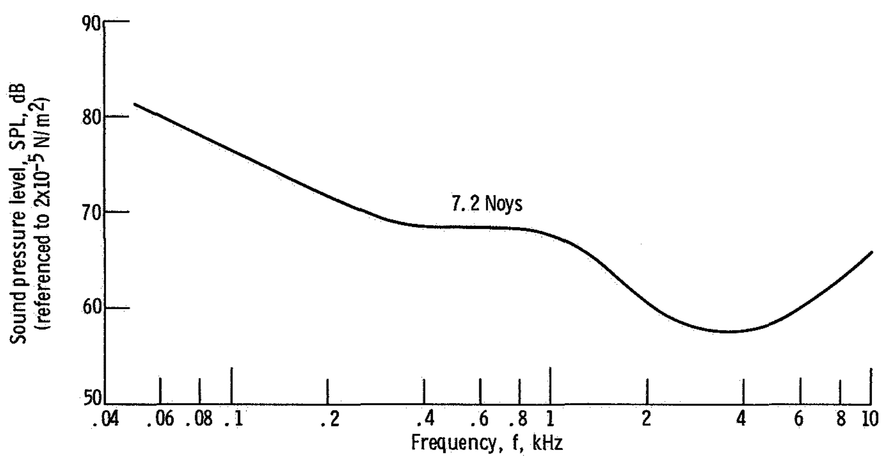


Figure 10. - Sound pressure level spectrum yielding a constant Noy value and 90 PNdB.

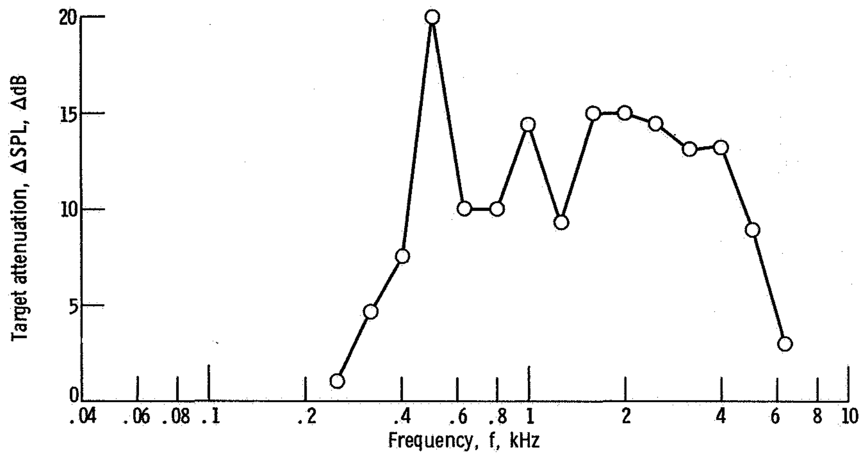


Figure 11. - Estimated target attenuation spectrum to reach 90 PNdB at 152.5-meter (500-ft) sideline and 120° from inlet direction for noise estimate of figure 3.

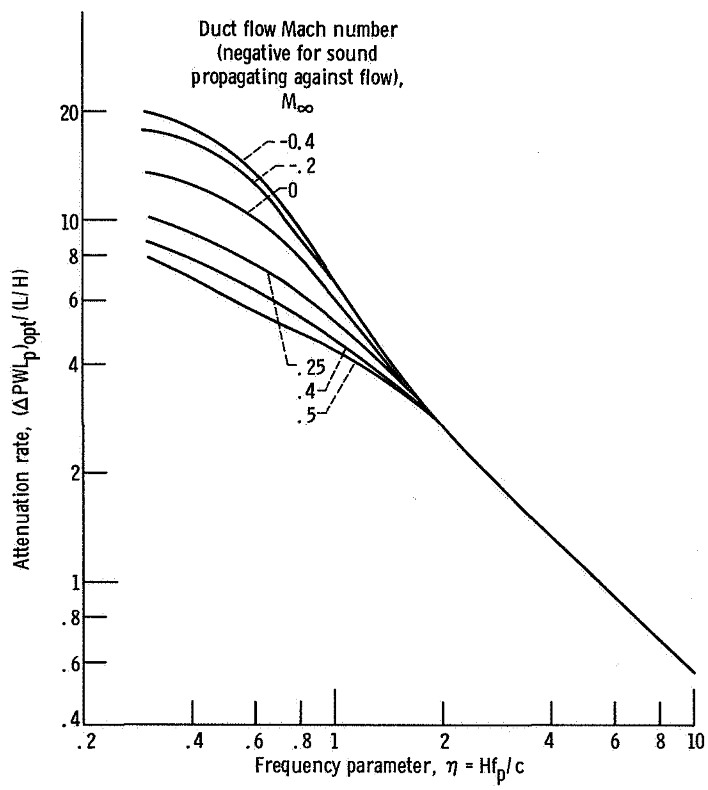


Figure 12. - Acoustic liner peak noise attenuation for least attenuated mode, optimum impedance in rectangular duct (empirically adjusted by 0.4 factor from theory).

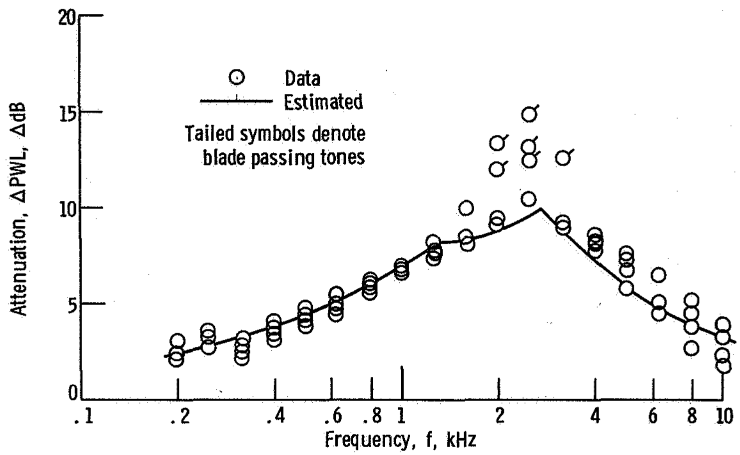


Figure 13. - Adjusted attenuation estimate compared with measured spectra at several speeds from QF-1A fan inlet tests from reference 18.

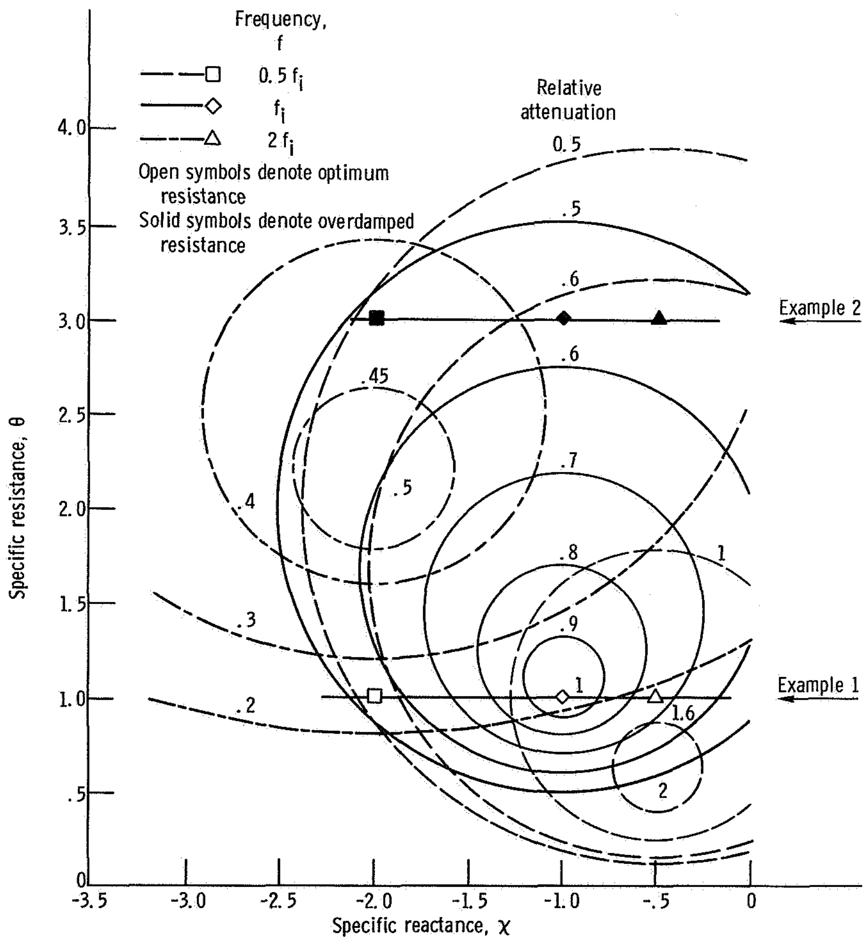


Figure 14. - Illustration of equal attenuation contours and liner impedance model for three different frequencies. (Circles are approximations to actual curves.)

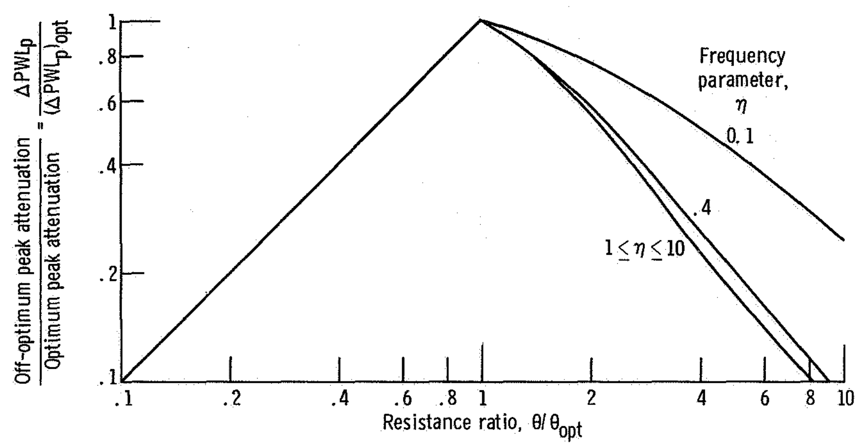


Figure 15. - Peak attenuation ratio (at peak frequency) for off-optimum resistance and optimum reactance.

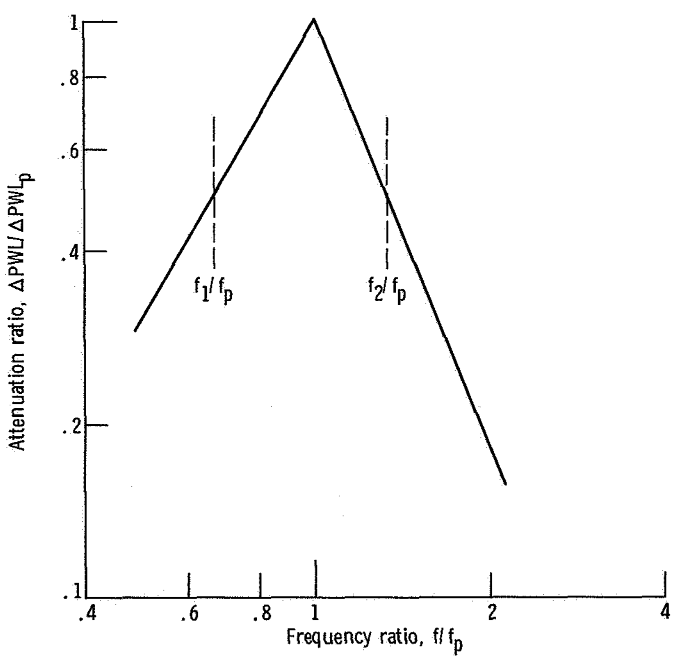


Figure 16. - Conceptual bandwidth curve showing f_1 and f_2 characteristics.

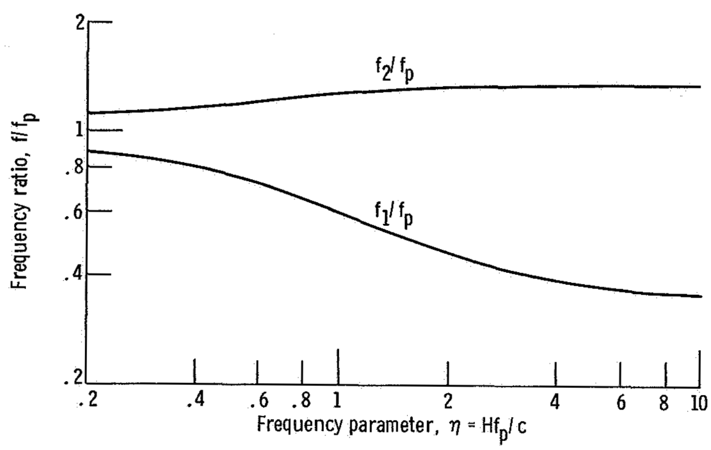


Figure 17. - Bandwidth characteristics for optimum resistance liner.

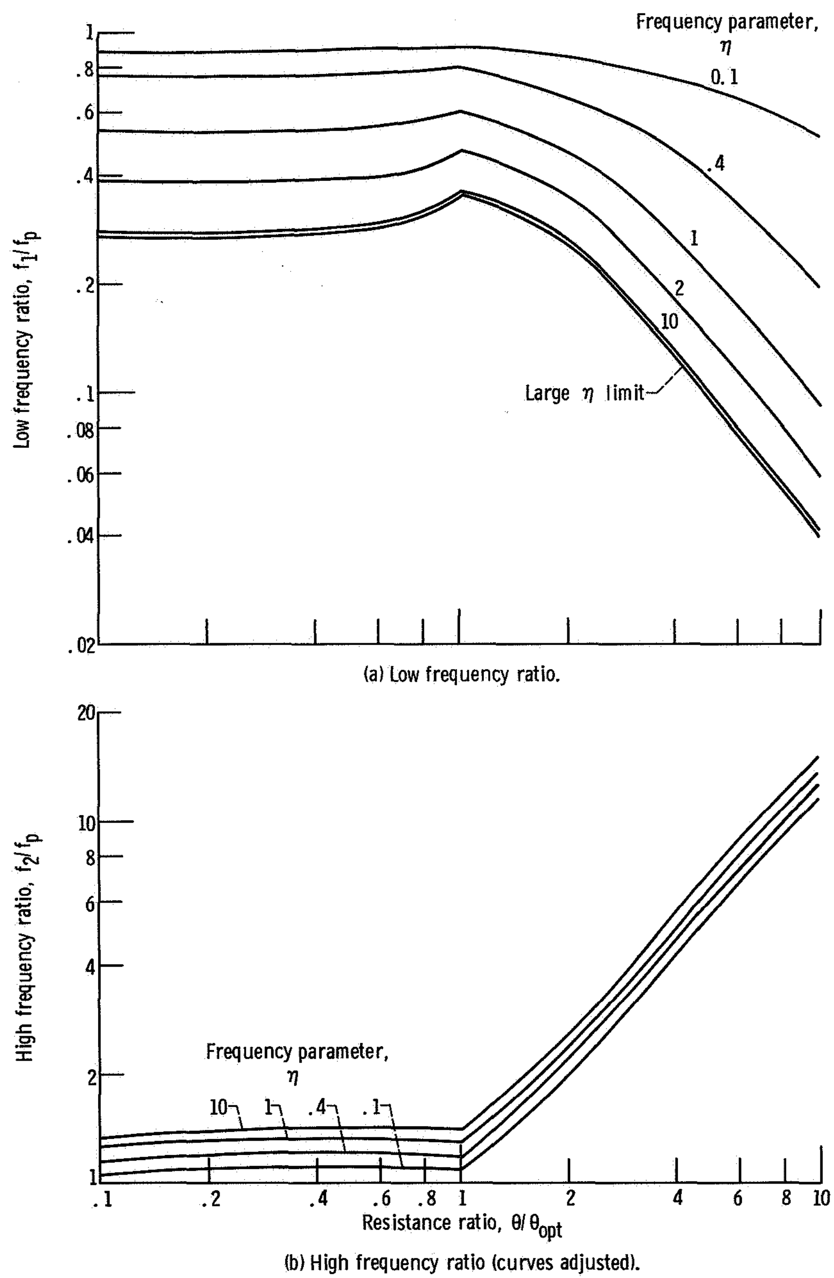


Figure 18. - Bandwidth as a function of resistance ratio and frequency parameter.

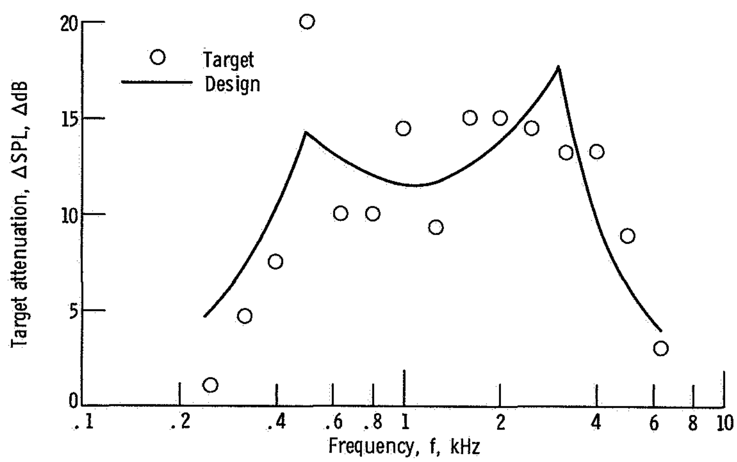
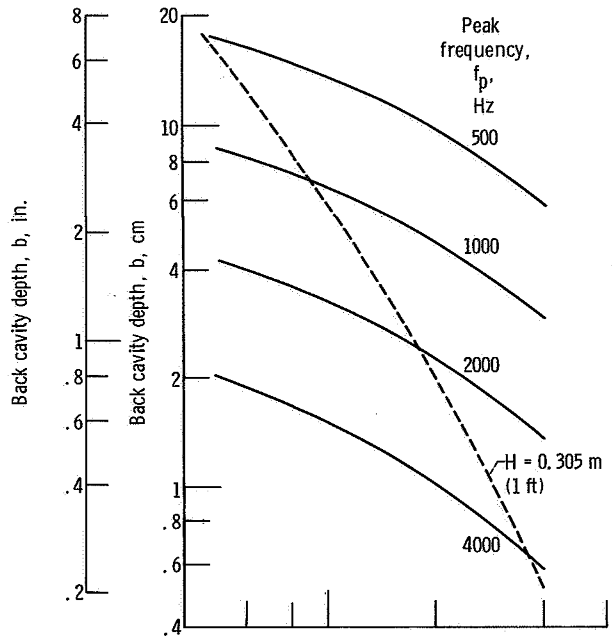
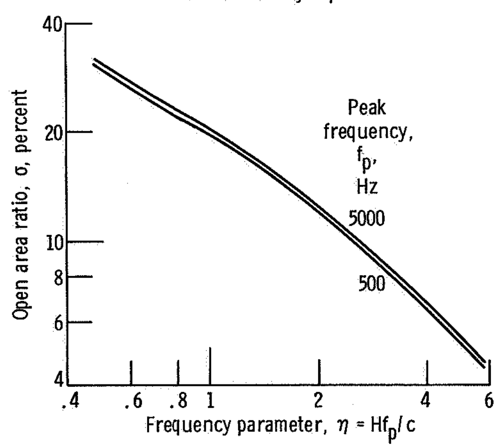


Figure 19. - Target attenuation spectrum and calculated design estimate spectrum for aft duct liner with 90-PNdB goal. Design estimate spectrum produces 89.5 PNdB.



(a) Back cavity depth.



(b) Open area ratio.

Figure 20. - Chart for liner wall selection for optimum impedance. Duct Mach number, M, 0.4; duct temperature, T, 288 K (519^0 R); static pressure, p, 1.013 N/m^2 (14.7 psia); overall sound pressure level, OASPL, 140 dB; sheet thickness, t, 0.051 centimeter (0.020 in.); hole diameter, d, 0.127 centimeter (0.050 in.).

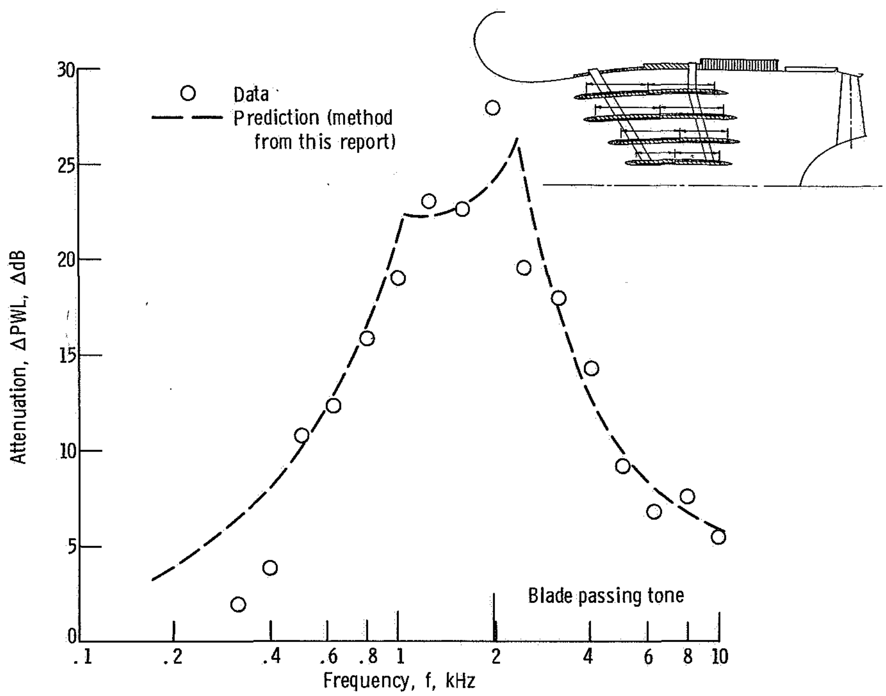


Figure 21. - Measured and estimated acoustic liner performance. General Electric Quiet Engine C inlet liner; 80 percent speed. (NASA unpublished acoustic tests.)

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