NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

TECHNICAL NOTE 4050

STUDIES OF STRUCTURAL FAILURE DUE TO ACOUSTIC LOADING

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SUMMARY

Some discussion of the acoustic fatigue problem of aircraft structures is given along with data pertaining to the acoustic inputs from some powerplants in common use. Comparisons are given for results of some fatigue tests of flat panels and cantilever beams exposed to both random- and discrete-type inputs. In this regard it appears that both the stress level of the test and the type of model are significant; hence, no generalization can be made at this time. With regard to increasing the fatigue life, it was noted that increased stiffening of a panel due to curvature and pressure differential is particularly beneficial.

INTRODUCTION

It is well-known that fatigue damage can occur to aircraft structures which are exposed to intense acoustic pressure loads. Damage usually occurs in the secondary structure of the aircraft as a result of a large number of relatively small loads applied at the rate of several hundred loading cycles per second. This paper presents information pertaining particularly to the problem of exposure to random noise such as that encountered from turbojets, ram jets, rocket engines, and aerodynamic boundary layers.

Some of the phenomena involved in this problem can be discussed with the aid of the block diagram of table I. Let us first direct our attention to the blocks themselves. The acoustic inputs are in the form of fluctuating pressures on the exposed surface of the structure. They impose loads that tend to vibrate the surface. Depending on its structural characteristics, such as geometry and method of construction, the surface will have a certain dynamic response. This dynamic response influences the stress patterns in the structure which, in turn, determine the fatigue life.

Analyses have been published (refs. 1 and 2) wherein the phenomena denoted as A in table I were used to calculate stresses on a simple panel. A knowledge of the noise spectra at an arbitrary point and the dynamic response to a uniform load have made it possible to calculate, by spectral techniques, the stresses at an arbitrary point on the panel. For more complex structures or inputs or both, this approach may not be sufficient and it may thus be necessary to use the quantities denoted as B in table I for the stress analyses. For instance, a knowledge of the correlation functions of the acoustic input and the complex dynamic influence coefficients of a panel surface might make it possible to calculate the stress distribution over the surface.

Thus, it is seen that the blocks in table I each represent rather complex phenomena. Detailed analyses of all parts of this problem would involve considerable effort and are beyond the scope of this paper. The rest of this paper will deal mainly with the fatigue life of structures exposed to noise and, in particular, will compare results of random and discrete frequency fatigue testing. The other parts of the problem are discussed only briefly.

SYMBOLS

d	nozzle diameter
x	axial distance measured from nozzle exit plane
$\Phi_N(\omega)$	power spectral density of noise input
$Z(\omega)$	mechanical impedance of panel
$\Phi_\sigma(\omega)$	power spectrum of stress in panel

ACOUSTIC INPUTS

The ingredient of this problem which differentiates it from other fatigue problems is the nature of the input function. This can be described briefly with the aid of figure 1. Shown here are the acoustic inputs for various powerplants in common use. The data shown are the noise pressure loads on a surface parallel to the thrust axis of the engine and four exit diameters distant from it. (Free space measurements were increased by 3 decibels to adjust them to conditions at the surface of the wall.) Both the noise pressure levels in decibels and the equivalent noise pressures in pounds per square foot are given on the vertical scale as a function of distance from the exit nozzle of the engine. Surface pressure data are given for two turbojet engines and one rocket engine. It should be noted that the numbers associated with the coded legend are the pounds of thrust developed by the engine per square foot of nozzle exit area. The short solid turbojet curve applies to an engine operating at a pressure ratio across the nozzle of 2.0 whereas the curve of long dashes applies to the engine for which free-space data are given in reference 3 and which operated at a pressure ratio of 2.2. These two curves illustrate the growing severity of the problem as the engine performance increases because of the increased engine pressure ratio. The curve of long-short dashes applies to a World War II rocket engine. It is seen that these pressures are of the order of 10 decibels higher than those for the turbojet engine with the 2.2 pressure ratio. For rocket engines operating at higher pressure ratios, there is some evidence that the acoustic pressure would also tend to be higher. All these engines generate intense noise in the range of frequencies that is detrimental to aircraft structures. For the type of random spectra generated by these engines, fatigue damage can occur at overall levels of the order of 140 decibels or higher. The amount of damage incurred at any given level, of course, is a function of the (1) detail design of the structure, (2) the length of exposure to the noise, and, also, (3) the spectrum of the noise.

DYNAMIC RESPONSE

The importance of the noise spectrum with relation to the dynamic response of a given structure is illustrated by the diagrams of figure 2. Conditions are defined for tests of flat panels exposed to discrete frequency noise from a siren and to random noise from a jet.

The input spectra of figure 2 are related to the stress spectra by the panel admittance. It can be seen that the noise from the siren was contained largely in the fundamental frequency, the harmonics being few in number and relatively weak. For these tests the siren was tuned until the fundamental frequency coincided with the first natural mode of the panel. As a result nearly all the energy accepted by the panel is in its first mode. A panel being excited by the broad-band spectrum of the jet, on the other hand, responds in some degree to all frequencies.

It can be seen from an inspection of the figure that a panel will accept essentially all the energy available from the siren whereas a large part of the energy available from the jet is not accepted. For these particular tests, the stress developed by a discrete-type excitation would be expected to be greater at a given overall noise pressure.

FATIGUE LIFE

Effects of Overall Noise Level

Some fatigue results obtained for panels exposed to both of these types of input are given in figure 3. Fatigue life as a function of the overall noise level is shown for an 0.032-inch gage flat panel 11 inches by 13 inches mounted over a rectangular cutout in a rigid frame. The panel was attached by small round head bolts tightened to a predetermined torque. This configuration was chosen for the reason that it facilitated assembly and disassembly of models while stress concentrations similar to those in a riveted structure were retained. For the solid points which represent fatigue data obtained with the siren, the curve has been sketched in through the available points to indicate a general trend of the data. Fatigue life is very strongly dependent on the level of noise excitation, since it varies from under a minute to several hours in the noise-level range of the tests.

Attention is called particularly to the open points which are data obtained with the jet. These data fall generally to the right of the curve in figure 3; thus, a longer fatigue life is indicated. This difference in fatigue life is due in part to the fact that the panel has a higher root-mean-square stress level when excited by the siren for a given overall noise level than when excited by the air jet.

Effects of Method of Mounting

During the discrete frequency tests with these simple panels, the opportunity was taken to change the manner of mounting to evaluate possible effects on fatigue life. These mounting configurations are shown schematically in figure 4 along with some of the test results in bar graph form. For all the mountings, the gage and size of panel were constant and the input noise levels were also constant. The basic configuration A is the same as that for which data were presented in figure 3. Failures in the skin panel occurred first near the bolt heads and the average fatigue life for this configuration is used as a reference in the figure.

Configuration B is the same as configuration A except that a layer of bonding material is placed between the panel and the rigid frame. During testing, the panel first peeled away from the bonding and then failure in the skin occurred near the bolt heads. This configuration lasted on the average about 50 percent longer than configuration A. An attempt was made to eliminate peeling by bonding both sides and clamping the panel between two rigid surfaces as in configuration C. In this case failure occurred at the edge of the frame and the average model lasted twice as long as configuration A.

In order to study the effects of curvature some panel models were rolled to an 8-foot radius and were fastened for testing to a curved rigid frame as indicated in configuration D. Failures were initiated near the bolt heads as in configurations A and B. This condition resulted in an average life about 15 times as long as for configuration A even though the frequency of the stress cycles increased by about 50 percent. A further increase of fatigue life was obtained by leaving the edges of the frame sharp instead of rounding as in the figure. This latter scheme caused the failures to occur at the edge of the frame instead of at the bolt head; by so doing the fatigue life was doubled as indicated by the bar of dashed lines. Configuration E is the same as configuration D except that tests were made with a pressure differential of 6 pounds per square inch across the panel. This high internal pressure caused the first panel frequency to nearly treble and the fatigue life was greatly increased as shown, in spite of the much faster rate of application of stress cycles.

As a matter of interest a 0.064-inch-gage panel was tested in a configuration similar to configuration A for comparison. It was found that doubling the gage thickness of the panel increased its fatigue life to about twenty times that of configuration A. This finding was confirmed in both the jet and siren tests.

A limited number of other tests have been made on larger and more complex panels. In all cases failures came first in the stiffener elements; thus, the importance of detail design of the panel supporting structure is emphasized. It was also noted that crack growth was markedly more rapid in bonded structures than in riveted structures.

Comparison of Random and Discrete Frequency Tests

Flat panels.- The rest of the paper will deal with comparisons of fatigue life under discrete and random loading at the same root-mean-square (RMS) stress levels. The results of flat-panel tests are given in figure 5. Time to failure in hours is shown for various root-mean-square stress levels for an 0.032-inch-gage panel. The solid points were obtained by means of discrete frequency excitation from a siren whereas the open points were obtained with random excitation from an air jet. The curve is a least-square curve through the solid points. It can be seen that at a given root-mean-square stress level, failure occurs in a shorter time when the panels are excited by the random jet noise. The fact that the random noise of the jet is more destructive may result from the fact that some of the peak stress responses are several times as great for a given root-mean-square value as they are for the constant-level siren tests. This phenomenon is particularly noticeable at the lower stress levels where the differences in fatigue life tend to be the greatest and the panel damping is relatively low. At higher stress levels the panel damping is greater and the differences in fatigue life tend to be smaller.

Cantilever beams.- Similar fatigue tests have been made for notched cantilever beams at various stress levels for both random- and discrete-type inputs. A schematic diagram of the model along with some of the test results are illustrated in figure 6.

Here again the time to failure in hours is shown at various root-mean-square stress levels for the beams tested in bending. The specimens were 3 inches long, 1 inch wide, and 1/4 inch deep with 3/16-inch notches located 1/2 inch from the root. The open points were obtained by means of an amplified tape recording of jet noise fed into a shaker attached to the tip. The solid points were obtained by applying a sinusoidal load at the tip in a Sonntag bending fatigue machine. There is a tendency in these tests also for the random load to be relatively less destructive at the higher stress levels and more destructive at the lower stress levels than the sinusoidal load. For the data of figures 5 and 6 the strain-gage locations were arbitrary and hence the root-mean-square stresses shown in figures 5 and 6 are not necessarily comparable.

A theoretical prediction of the time to failure for the random loading is given by the solid curve. This theory is essentially one given by Miles (ref. 1) and is based on Miner's rule of linear accumulation of damage. It can be seen that this theoretical curve fits the data fairly well at low stress levels but is very conservative at the higher stress levels.

CONCLUDING REMARKS

The problem of acoustic fatigue of aircraft structures has been discussed with particular emphasis on a comparison of the fatigue life due to discrete- and random-type loadings. In this regard it appears that both the stress level of the test and the type of model are significant; hence, no generalizations can be made at this time. With regard to increasing the fatigue life, it was noted that increased stiffening of a panel due to curvature and pressure differential is particularly beneficial.

Langley Aeronautical Laboratory,
National Advisory Committee for Aeronautics,
Langley Field, Va., March 7, 1957.

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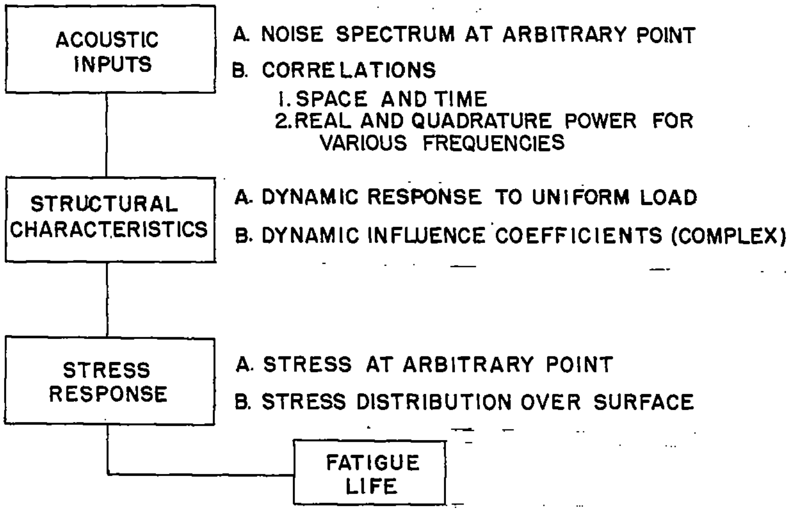
2. Lassiter, Leslie W., Hess, Robert W., and Hubbard, Harvey H.: An Experimental Study of the Response of Simple Panels to Intense Acoustic Loading. Jour. Aero. Sci., vol. 24, no. 1, Jan. 1957, pp. 19-24, 80.

3. Howes, Walton L., and Mull, Harold R.: Near Noise Field of a Jet-Engine Exhaust. I - Sound Pressures. NACA TN 3763, 1956.

TABLE I

ACOUSTIC FATIGUE PROBLEM



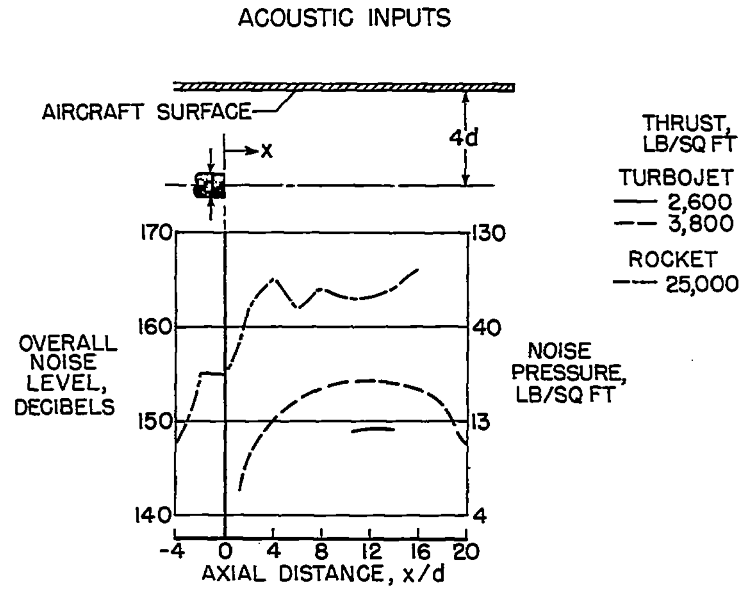


Figure 1

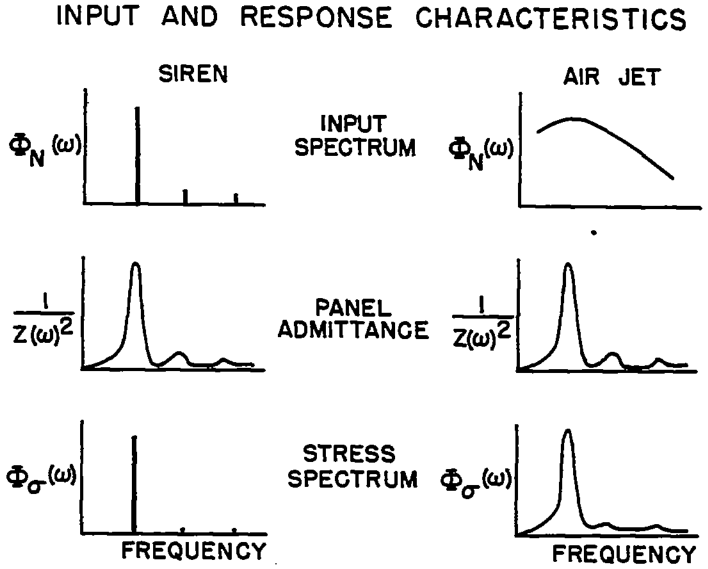


Figure 2

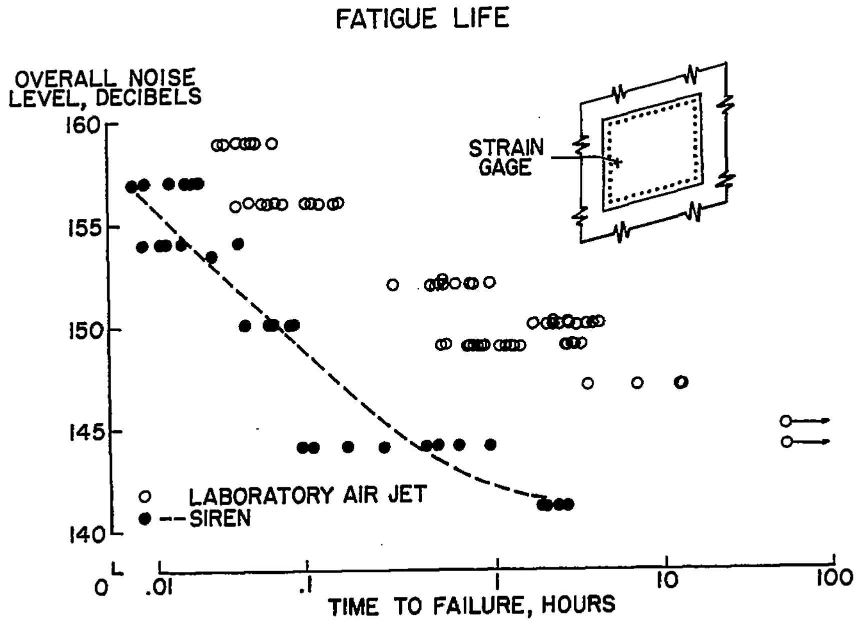


Figure 3

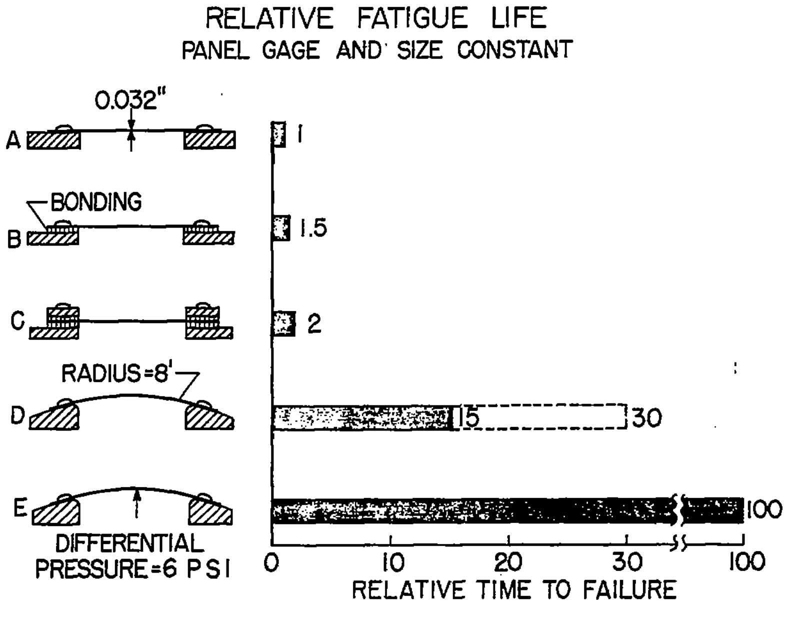


Figure 4

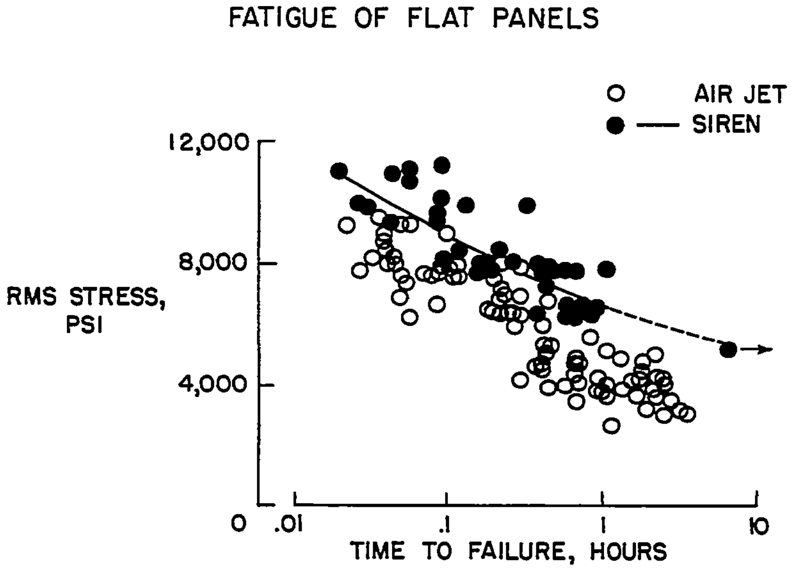


Figure 5

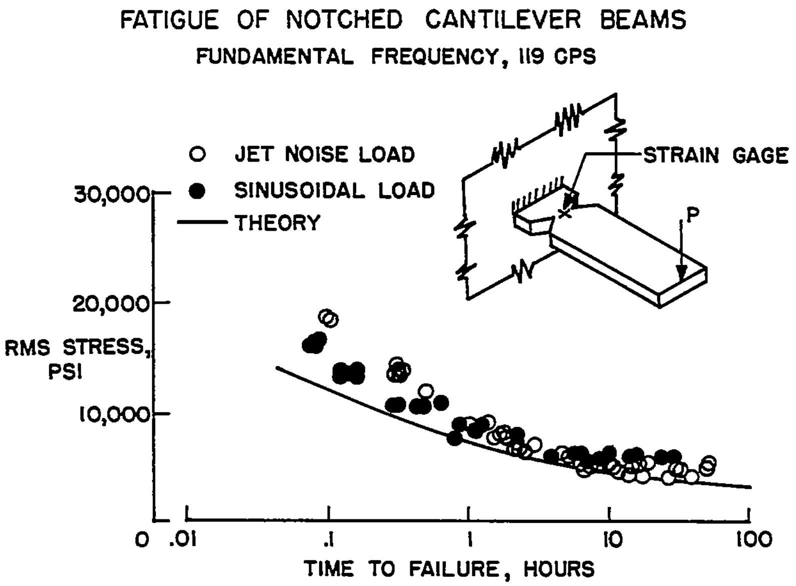


Figure 6

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