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SOME MEASUREMENTS OF NOISE TRANSMISSION AND STRESS RESPONSE OF A 0.020-INCH DURALUMIN PANEL IN THE PRESENCE OF AIR FLOW

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SUMMARY

Noise transmission measurements were made for a 0.020-inch panel with and without air flow on its surface. Tests were conducted with both an absorbent and reverberant chamber behind the panel. Panel stresses for some of these tests were also determined. Noise spectra obtained inside the absorbent chamber with flow attached and flow not attached to the panel appeared to contain several peaks corresponding in frequency to panel vibration modes. These peaks were notably absent when the chamber was reverberant.

The noise reduction through the test panel measured with the aid of an absorbent chamber for the flow-not-attached case is in general agreement with values predicted by the theoretical weight law, which assumes negligible panel stiffness. Corresponding data for the flow-attached case do not follow the weight law but rather indicate less noise reduction at the high frequencies. The main stress responses of the panel without air flow occurred at its fundamental vibration mode. In the presence of air flow the main response occurs in a vibration mode having a node line perpendicular to the direction of air flow.

INTRODUCTION

One of the most important sources of noise in the interior of the aircraft during its high-speed flight is the boundary layer. This noise arises from the pressure pulses in the boundary layer which are transmitted through the skin of the airplane to the interior compartments. The intensity of this noise increases with increased airspeed; therefore, the problem may become more serious for future high performance airplanes. (See ref. 1.) Several studies have been made of the physical characteristics of the boundary-layer pressure fluctuations, as indicated in references 2 to 6. The part of the problem that is of most practical interest with regard to passengers and crew members concerns that part of the boundary-layer noise which is transmitted through the fuselage skin and into the cabin rather than the part that is radiated into the free stream. The problem, then, involves an interrelation of the physical characteristics of the noise pressure field with the response characteristics of the skin surface. Not much information is available, however, on the behavior of panels exposed to this type of noise and the mechanism by which these pressure pulses are transmitted through a panel.

The phenomenon of panel response to a boundary-layer noise excitation has been studied theoretically in reference 7. It is assumed that L
the turbulent pressure distribution on the outside of the panel can be 6
represented as a pattern of moving waves. A running ripple in the skin 0
follows underneath each wave, and this ripple can be reflected at the 9
frames and stringers. The noise is thought to result, not from the running ripples, but from the reflections which can cause standing waves in the skin. A similar theoretical study in reference 8 deals with the transmission of boundary-layer noise to the inside of a fuselage. In this study it is assumed that a multitude of external pressure pulses push the elastic skin in and out, and the skin in turn, like a set of distributed pistons, creates pressure waves inside the fuselage which propagate and superimpose to constitute the noise field.

Experimental data for the radiation of noise by a panel subjected to a boundary layer on its outside surface are given in reference 9. These experiments, which were carried on at low Mach numbers with the aid of a special acoustic wind tunnel, indicated that the sound power radiated by the panel varied with the air-stream velocity from the third to the fifth power. The noise was noted to have a broad continuous spectrum, the peak frequency of which increased as the stream velocity increased.

With regard to the panel stress response due to boundary-layer noise, the theoretical work of reference 10 is cited. Account is taken of the effect of a steady air-flow component on which is superposed a random loading of constant intensity but which varies in phase over the panel surface. It was found that the fundamental vibration mode of the panel was the main source of stress and that the stress amplitude increased markedly as the panel flutter speed was approached.

The purpose of this paper is to present some results of studies of the effects of air flow on the noise transmission and stress response characteristics of a thin flexible panel. It is believed that these results are applicable to problems of transmission of noise through skin surfaces in the presence of air flow and the fatigue problem of aircraft skin surfaces due to boundary-layer noise.

EQUIPMENT AND MEASURING TECHNIQUES

The laboratory equipment used for studying the noise-transmission characteristics of flat panels and the general test arrangement are shown in figure 1. The test panel is mounted on an acoustic chamber and is positioned in such a way that air issuing from a slit nozzle flows generally parallel to the surface of the panel and may either be attached to the panel surface or not, depending on the test conditions. The equipment located upstream of the nozzle consisted of a muffler to eliminate the valve noise and a settling chamber. Measurements of the jet noise were made both outside and inside the chamber for two air-flow conditions. Other measurements taken were the strains at two locations on the edge of the panel for the two air-flow conditions and for both an absorbent and reverberant acoustic treatment inside the chamber. The following sections describe in more detail the test panel, the acoustic chamber, the instrumentation, and the noise environment.

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Description of Test Panel

A simple flat 0.020-inch-thick duralumin panel was used for the noise-transmission and stress-measurement tests. The overall size of the panel was 5 inches by 10 inches with a free area of 3 inches by 8 inches as shown in figure 2. The frame was cut from a piece of solid duralumin having a thickness of about 3/4 inch. The panel was bonded to this frame with Teflon cement, and the frame in turn was bolted to the cover plate of the chamber.

The vibration characteristics of the panel were obtained experimentally by exciting the panel with a loudspeaker driven by a sinusoidal input. The resonant response of the panel was observed by means of sand sprinkled over its surface. The node lines for each response and the corresponding loudspeaker frequency are presented in table I. The frequencies associated with the various vibration modes were calculated by the method of reference 11 and are also listed in table I. Frequency calculations were made for all possible modes up to 2,400 cycles per second and also for the principal vibration modes observed in the range 2,400 to 10,000 cycles per second during static vibration tests. Modal patterns 6, 7, and 8 of table I were not excited during static vibration tests, but frequencies associated with these modes were prominent in the strain responses during air-flow tests.

A comparison between the measured and calculated natural vibration frequencies is given in figure 3. The data points are noted to be within about ±10 percent of the line of perfect agreement for the whole range of frequencies.

Instrumentation

Three condenser-type microphones were used to obtain the sound-pressure levels outside and inside the test chamber. The sound-pressure range of these microphones extended from 83 to 179 decibels. The microphone inside the chamber was positioned 5 inches below the panel and was centrally located with respect to the panel. This microphone responded mainly to sound transmitted through the test panel, the sound transmission through the chamber walls having been minimized because of their construction. The other two microphones were shock-mounted in such a way as to measure the surface pressures on a rigid plate located at the panel test position, as shown in figure 4. These two microphones had effective circular diaphragm areas corresponding to diameters of 0.04 inch and 0.625 inch, respectively.

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Data from the strain gages were obtained in the frequency range of 100 to 10,000 cycles per second with the aid of the equipment shown in the block diagram of figure 5. A slide-wire potentiometer and an a.c. precision calibrator were used, respectively, for balancing the Wheatstone bridge and calibrating the system. An a.c. transistorized voltage amplifier was used to amplify the relatively weak strain-gage signals. Some of the data from the microphones and strain gages were recorded on magnetic tape. Spectral analyses were obtained directly or from the magnetic tape records with the aid of a one-third-octave bandwidth analyzer and a level recorder.

Description of Acoustic Chamber

A sectional view of the specially designed acoustic chamber used in the present tests is shown schematically in figure 6. The walls were constructed of 1-inch plywood sheet with a 1/4-inch-thick asbestos sheet lining. The test panel was mounted off-center on a removable top which was shock-mounted to the chamber. The whole chamber, in turn, was shock-mounted to minimize vibrations.

Smooth, hard, wooden wedges are cemented to three interior walls of the chamber to eliminate parallel surfaces and thereby tend to rationalize the formation of standing waves. In this condition it can be used as a reverberant chamber whereas, if the interior is lined and filled with loosely packed fiber glass, it has the characteristics of an absorbent chamber. In the reverberant condition the volume of the chamber is 1.6 cubic feet and its internal surface area is 5.9 square feet. In this condition it has a measured reverberation time ranging from 0.68 to 0.25 second for frequencies in the range of 100 to 10,000 cycles per second, respectively.

As a matter of interest, data are presented in figure 7 to indicate the frequency characteristics of the test chamber with a rigid plate located in place of the panel. Measurements of sound from a 4-inch-diameter loudspeaker, mounted inside the cover of the chamber as noted in the sketch of the figure, were made over a range of frequencies for the microphone location used in the tests. These data were compared with data measured under otherwise similar conditions except that the lower portion of the chamber was removed. The differences between these two sets of data are plotted in decibels on the vertical scale of the figure as a function of frequency. The greatest deviation of 7 decibels was noted to occur at about 150 cycles per second.

In addition to its frequency-response characteristics, it is also desirable to evaluate the noise leakage through the walls of the chamber. Such data were obtained by replacing the test panel with a solid-aluminum-alloy plate having a thickness of 3/4 inch in order to minimize the transmission of noise through the test section. The internal noise spectra were then determined for the test conditions similar to those of the panel studies, and these data are shown in figure 8.

It can be seen that the ambient sound-pressure levels inside the chamber are generally higher for the test conditions for which the flow is attached to the panel. These differences are noted to occur mainly at the higher excitation frequencies. The levels in the reverberant chamber for both flow conditions tend to be somewhat higher than those for the absorbent chamber and contain some peaks which may be associated with chamber resonance. It should be noted that the measured spectra of figure 8 are generally lower than any spectra measured during the panel tests; thus it is concluded that the test results are not significantly affected by the noise-transmission characteristics of the chamber.

Noise Environment

The noise environments of these tests were generated by an unheated air-jet-exhaust stream operating at a nozzle exit Mach number of about 0.9. For convenience, a nozzle exit in the form of a long, narrow slit measuring 1/16 inch by 12 inches was used. Two positions of the noise source with respect to the panel surface were used in the tests. In one case the noise source was positioned 3 inches above the surface of the panel in such a way that there was no flow impingement, and, in effect, the panel was subjected to an acoustic field. In the second case the jet stream was positioned flush to the surface of the panel in such a manner that the flow attached to and flowed along the panel surface. The panel was thus exposed to a combination of acoustic and aerodynamic excitation. These two test conditions are referred to in this paper as "flow not attached" and "flow attached," respectively.

In order to define the input spectra to the test panel and to compare the physical characteristics for the two different test cases, surface-pressure measurements were made on a rigid 3/4-inch-thick plate positioned in place of the test panel and for the same operating conditions. Measurements were made with microphones having sensitive elements of 0.04- and 0.625-inch diameter (see fig. 4) in order to get some information on the correlation functions of the inputs. These data are presented in the form of one-third octave band spectra in figure 9 L
for both test conditions. It may be seen that the surface-pressure 6
spectra are different for the two flow conditions, and this condition 0
is confirmed by the data obtained with both microphones. The differences 9
in the spectra at corresponding frequencies are relatively small for the data obtained with the small and the large microphones for the flow-attached case. The smaller microphone tended to give higher readings than the larger microphone, however, for the flow-not-attached case. This result suggests that the noise input is correlated over a smaller area for the flow-not-attached case than for the flow-attached case.

RESULTS AND DISCUSSION

Chamber Measurements

Noise measurements with the internal microphone positioned as in figure 6 have been made for the test chamber in both its reverberant and absorbent configurations, and these data are presented in figures 10 and 11 along with the respective surface-pressure spectra obtained with the 0.625-inch-diameter microphone replotted from figure 9. The data of figure 10 pertain to the condition of no flow impingement on the panel, that is, an acoustic excitation. The noise spectrum obtained for the chamber in its absorbent configuration is seen to be some 15 to 45 decibels lower than the surface-pressure spectra and to contain several peaks. Prominent peaks appeared at frequencies of about 150, 590, 2,400, and 7,000 cycles per second. These frequencies correspond to some of the panel vibration modes illustrated in table I. When this test was repeated for the test chamber in its reverberant configuration, a markedly different noise spectrum was obtained as shown in figure 10. Noise levels were measured and the shape of the spectrum was very similar in shape to the surface-pressure spectrum but about 10 to 23 decibels lower in level. Notably absent are some of the peaks previously observed for the absorbent chamber. Two rather broad peaks are noted to be present, however, and the frequencies at which these occur do not seem to correspond to any of the panel vibration modes of table I.

Similar measurements were also made for the test condition where the air flow was attached to the panel surface, and these data are shown in figure 11 for both the absorbent and reverberant chamber configurations. For the absorbent chamber test, the noise spectrum indicated sharp peaks at about 150 and 590 cycles per second and a broad peak in the vicinity of 2,000 to 2,600 cycles per second with a suggestion of an additional peak in the vicinity of 10,000 cycles per second. The noise spectrum above about 1,000 cycles is relatively higher in level for this flow-attached condition than for the corresponding results of figure 10 for acoustic excitation. The frequencies at which these latter peaks occur seem to correspond to several vibration modes of the panel as indicated in table I. This result suggests that the flow along the panel tends to excite many of its high-frequency modes.

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For the conditions of the reverberant chamber, the inside noise spectrum seemed to follow the general shape of the surface-pressure spectrum but was 5 to 10 decibels lower in level, as also noted in figure 11. As may be noted, the overall sound-pressure level of the surface pressures for the flow-attached case is 133 decibels (see fig. 11). This value is 8 decibels higher than the overall sound-pressure level of the surface pressures for the flow not attached (see fig. 10). The question therefore arose as to whether the differences in noise reduction might be associated with differences in overall sound-pressure level of the input, because of possible nonlinearities in the panel. To answer this question, a test was made with the flow attached, but with the air velocity reduced; thus, the overall sound-pressure level corresponded to that for the flow-not-attached case. The results of this test showed that the noise reductions were within 2 decibels of those measured for the higher sound-pressure levels. Thus, there does not appear to be any appreciable effect of amplitude in the data.

Calculated Noise Reductions

The noise reductions through the test panel were calculated based on the measurements of figures 10 and 11 for the chamber in its highly absorbent condition, and these results are presented in figure 12. The data for the two curves presented in figure 12 were obtained by subtracting the measured inside noise spectrum for the absorbent chamber from the corresponding surface-pressure spectrum of figures 10 and 11. Also included in figure 12 for comparison is the classical weight law curve for the test panel as presented in reference 12. It is assumed in the weight law derivation that the attenuation characteristics of the panel are mainly a function of its surface density, stiffness effects being negligible. It may be seen that the resulting data of the flow-not-attached case scatter about the theoretical weight law values. The corresponding data for the flow-attached case do not, however, follow the theoretical weight law curve. These data tend to be higher at the low frequencies and lower at the high frequencies than the weight law would indicate. These deviations from the weight law curve suggest that the presence of air flow on the panel surface tends to excite the high-frequency modes in the panel. This deviation is in agreement with the results of the internal and external noise measurements for the B-47 airplane for ground run-up and flight conditions as reported by McLeod and Jordan. (See ref. 5.) Differences between the internal and external measurements of reference 5 were larger at the higher frequencies than at the lower frequencies for the ground run-up condition; however, during flight the opposite result was obtained.

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Panel Stress Response

During the noise-transmission tests, the opportunity was taken to measure the stress response of the panel. The stress-response data in the frequency range from 100 to 10,000 cycles per second are shown in figure 13 for the reverberant chamber configuration for both flow conditions. The stress values are seen to be much higher for the test conditions where flow is attached to the panel than for the flow-not-attached case. The main stress response in both cases occurs at frequencies corresponding to some of the vibration modes noted in table I. For the flow-not-attached case, the main response occurs at about 500 cycles per second, which corresponds to the frequency of the fundamental vibration mode. When flow is attached to the panel, there is also a substantial first-mode response, but the main response is at about 1,600 cycles per second.

Narrow-band analyses of the strain records indicated several strong individual response peaks at frequencies corresponding to modal patterns 4 to 13 of table I. Because of the wide-bandwidth characteristics of the analyzer used for the data of figure 13, these individual responses tend to add up to the large peak seen in the figure. It is significant to note that relatively strong strain responses generally occurred for the modes having node lines perpendicular to the air flow. The stress levels and spectra presented in figure 13 for the reverberant chamber configuration are not markedly different for those obtained for the absorbent chamber. Strain data presented for the long side of the panel did not differ markedly from those presented in figure 13 for the short side.

It should be noted that the data in figure 13 were obtained with the aid of a one-third-octave band analyzer. The ordinate value plotted at each frequency represents a summation of all frequency components within the prescribed bandwidth. Since this bandwidth tends to increase as frequency increases, some of the individual stress peaks may be obscured. The overall stress values are 3,800 pounds per square inch and 440 pounds per square inch for the flow-attached case and flow-not-attached case, respectively, and are obtained from a voltage reading of the unfiltered strain-gage signal.

CONCLUDING REMARKS

Measurements of noise transmission and stress response have been made for a 0.020-inch-thick panel with and without air flow attached to its surface in the frequency range 100 to 10,000 cycles per second. The noise reduction through the test panel measured in an absorbent chamber is in general agreement with values predicted by the theoretical weight law for the flow-not-attached case. Corresponding data for the flow-attached case do not follow the weight law but rather indicate less noise reduction at the high frequencies. The main stress responses of the panel without air flow occurred at its fundamental vibration mode. In the presence of air flow the main response occurs in vibration modes having node lines perpendicular to the direction of air flow.

Langley Research Center,
National Aeronautics and Space Administration,
Langley Field, Va., June 2, 1960.

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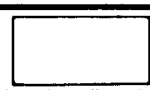
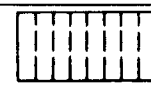
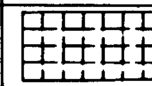
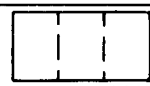
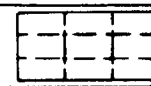
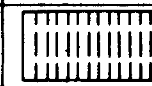
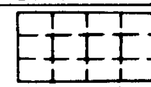
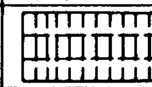
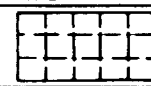
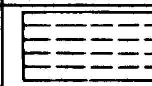
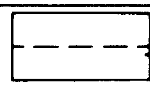
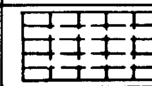
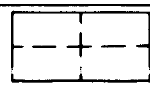
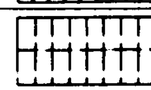
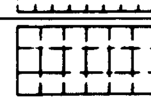
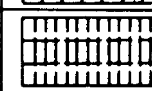
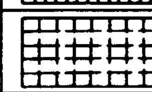
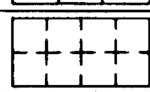
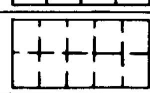
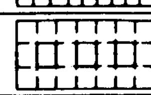
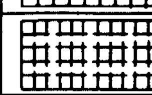
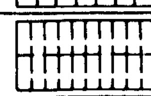
TABLE I.- NATURAL VIBRATION MODES AND FREQUENCIES OF THE TEST PANEL

Sand pattern	Vibration modes	Frequency, cps		Sand pattern	Vibration modes	Frequency, cps		Sand pattern	Vibration modes	Frequency, cps	
		Exp.	Calc.			Exp.	Calc.			Exp.	Calc.
1		490	504	13		2,400	2,388	25		5,100	5,385
2		590	588	14		2,680	2,465	26		5,500	5,666
3		840	732	15		2,710	2,885	27		5,950	5,764
4		1,145	945	16		2,850	3,084	28		6,200	6,236
5		1,400	1,227	17		3,140	3,343	29		6,450	6,518
6		—	1,370	18		3,200	3,002	30		7,000	7,217
7		—	1,452	19		3,300	3,247	31		7,500	7,915
8		—	1,574	20		3,500	3,665	32		7,700	7,710
9		1,625	1,591	21		3,800	3,601	33		8,000	8,355
10		1,700	1,792	22		3,840	3,773	34		8,200	8,858
11		2,100	2,057	23		3,900	4,051	35		9,100	10,049
12		2,200	1,984	24		4,450	4,362				

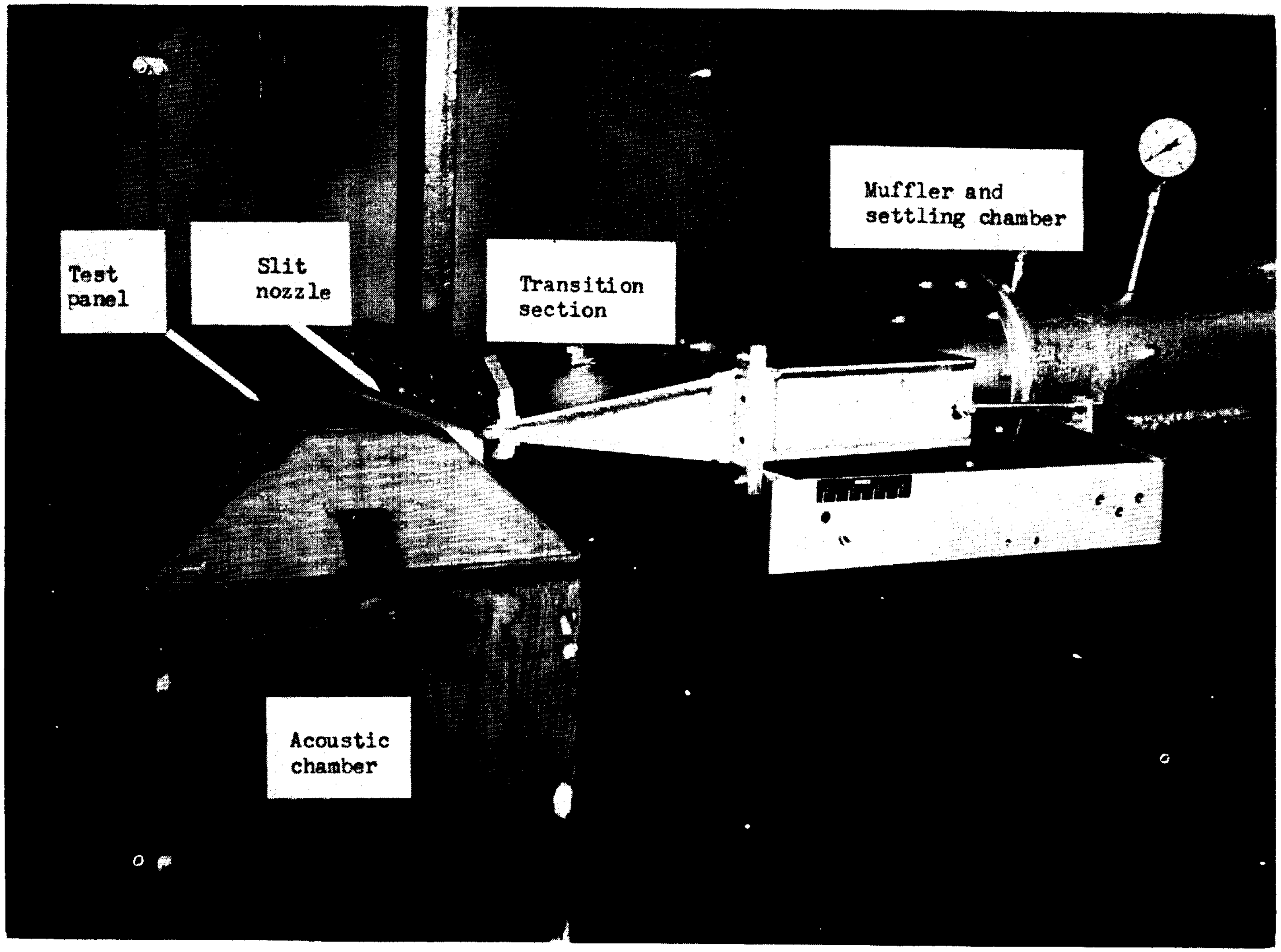


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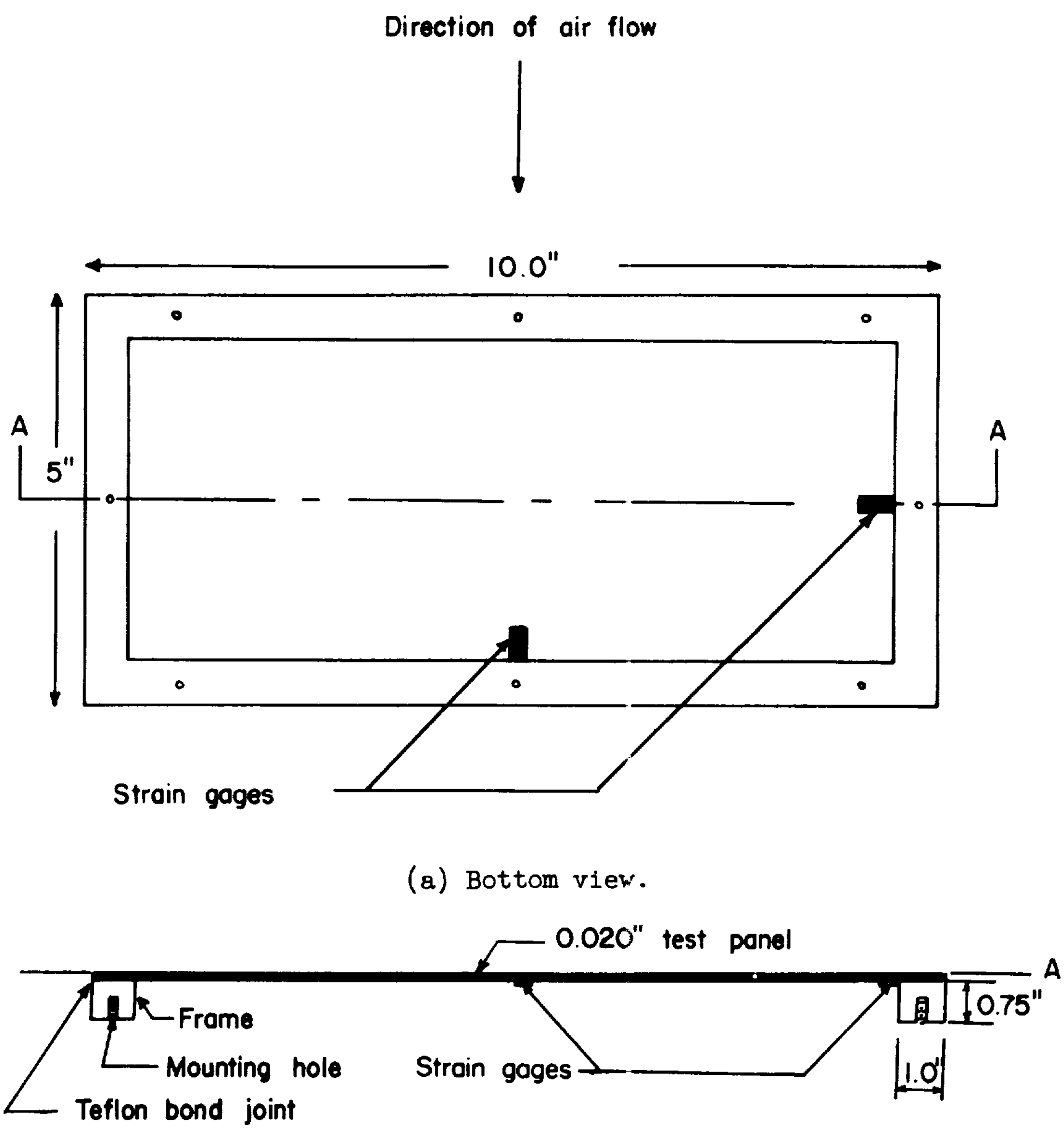
Figure 1.- Arrangement of apparatus for panel noise-transmission studies.



(a) Bottom view.

(b) Section view.

Figure 2.- Test panel for noise-transmission studies.

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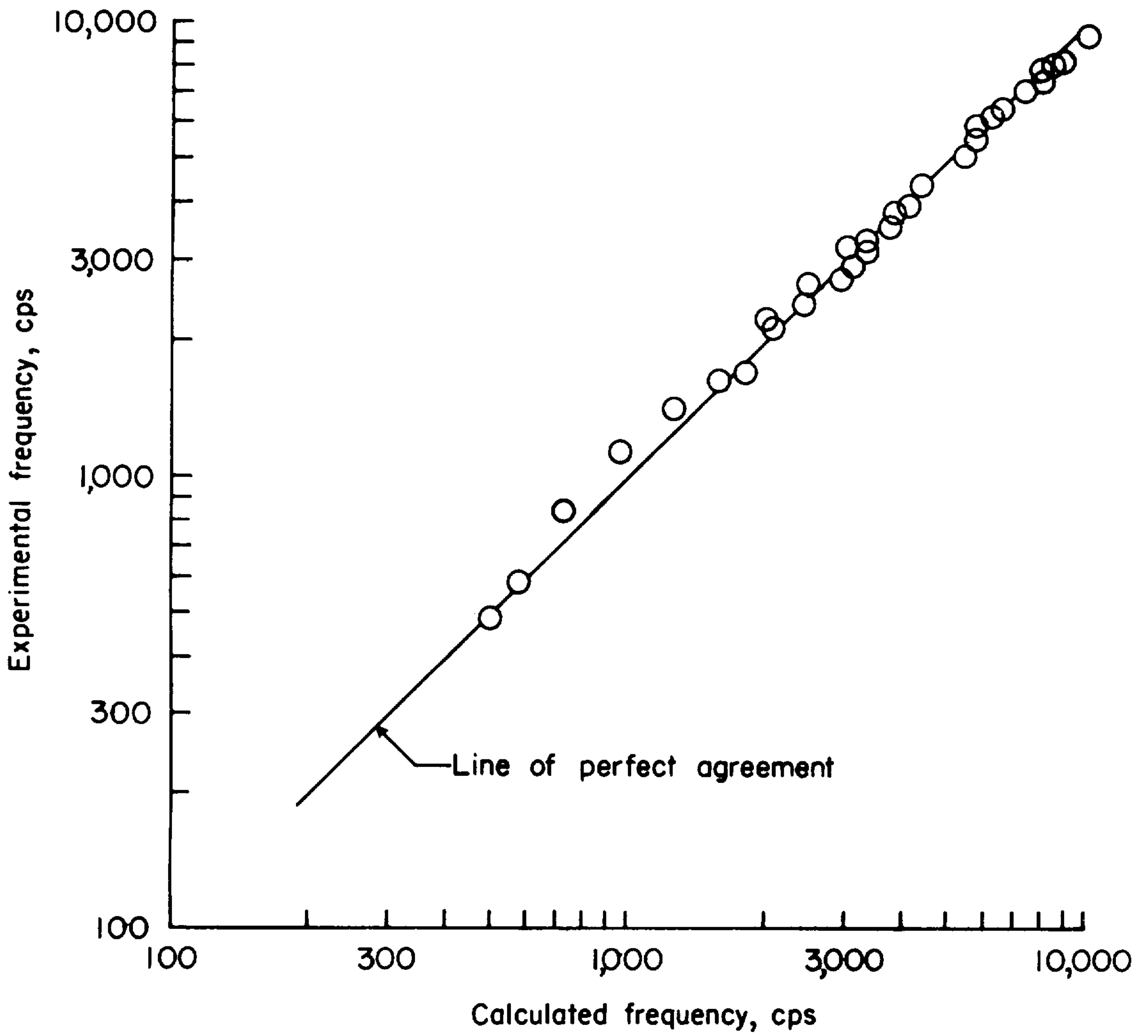

Figure 3.- Comparison of calculated and observed natural vibration frequencies of the test panel.

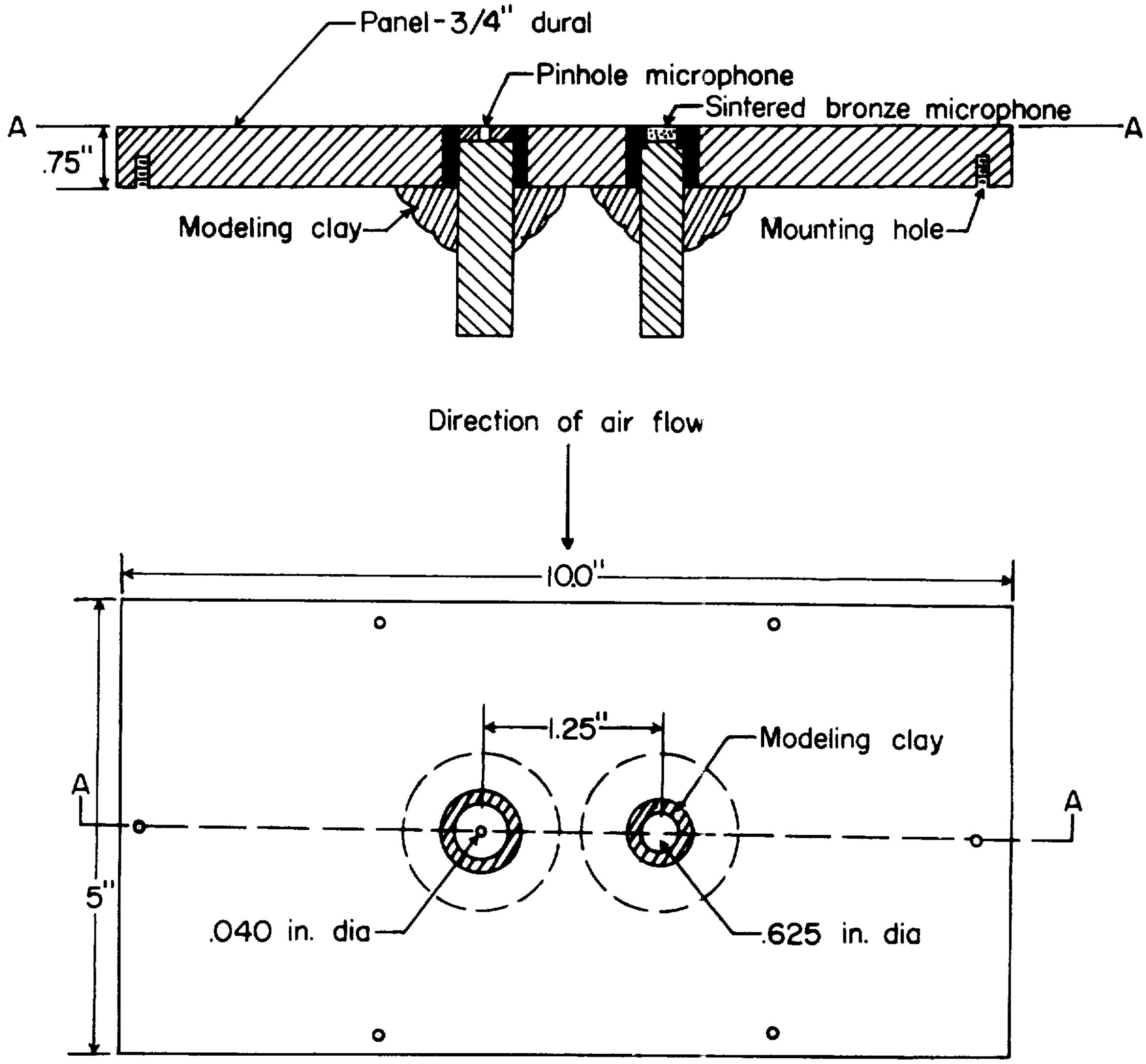

Figure 4.- Schematic diagram showing location and method of mounting of microphones for measuring surface pressures.

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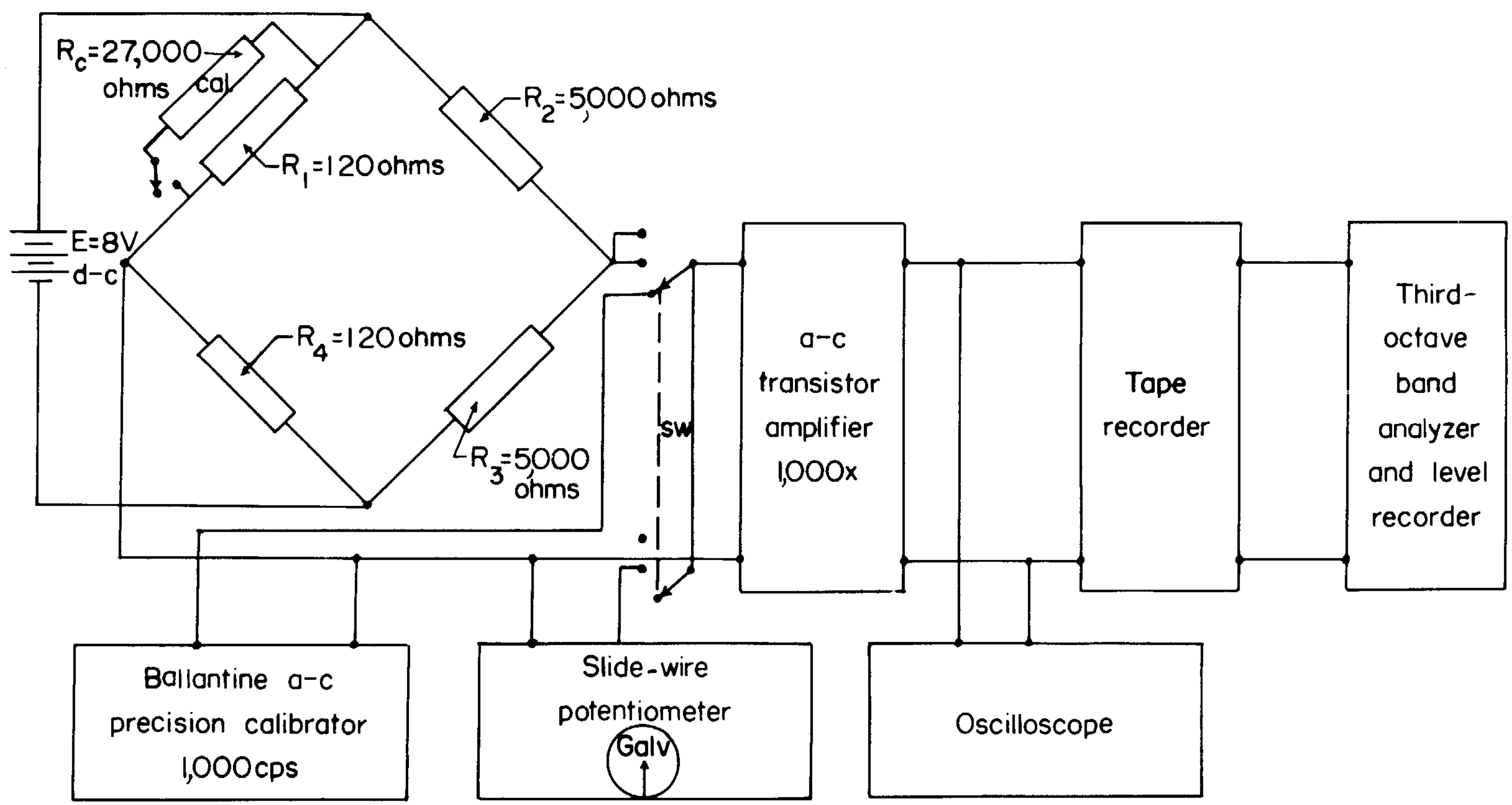

Figure 5.- Block diagram of strain-gage instrumentation.

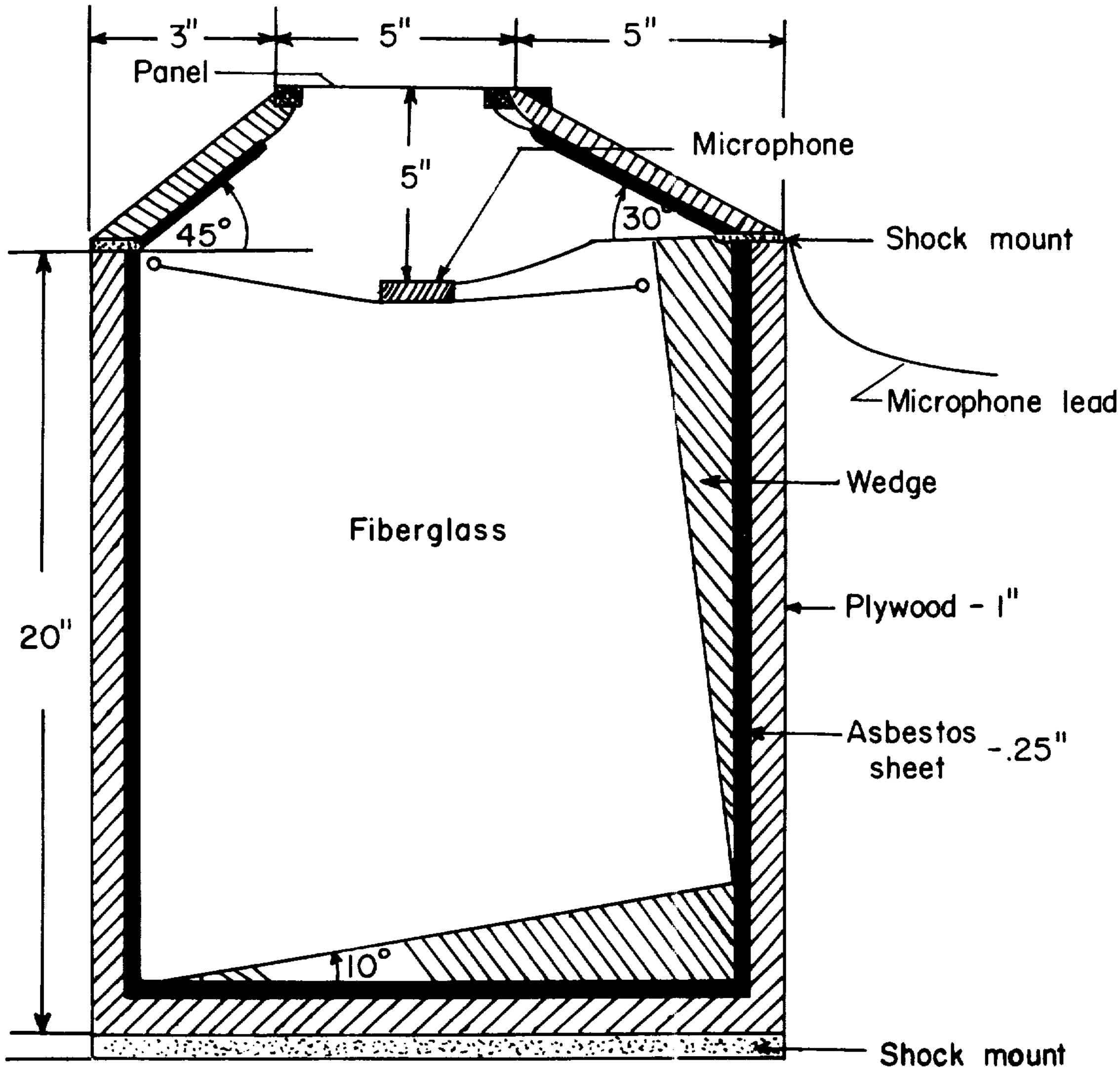

Figure 6.- Sectional view of acoustic chamber.

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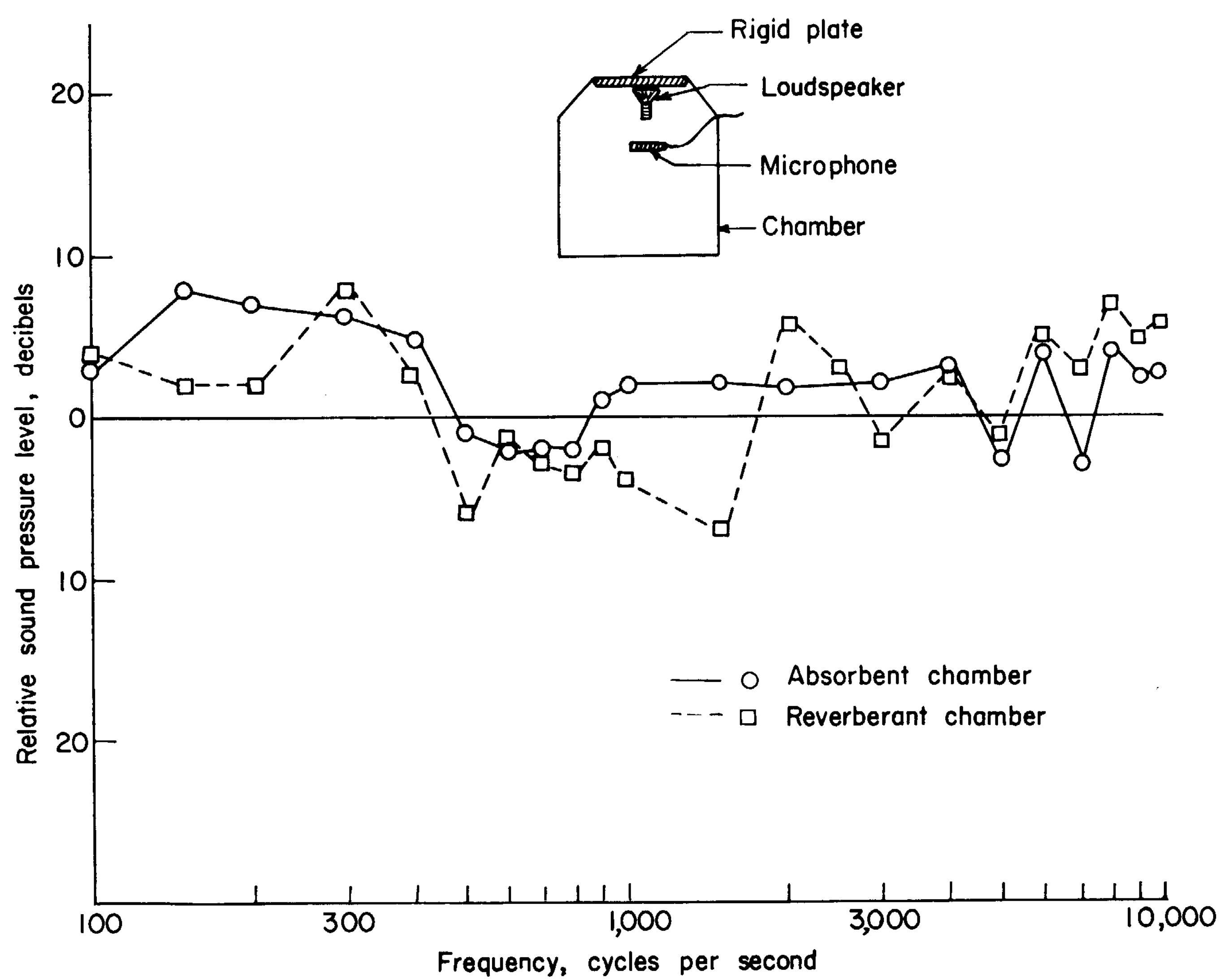

Figure 7.- Frequency-response characteristics of test chamber.

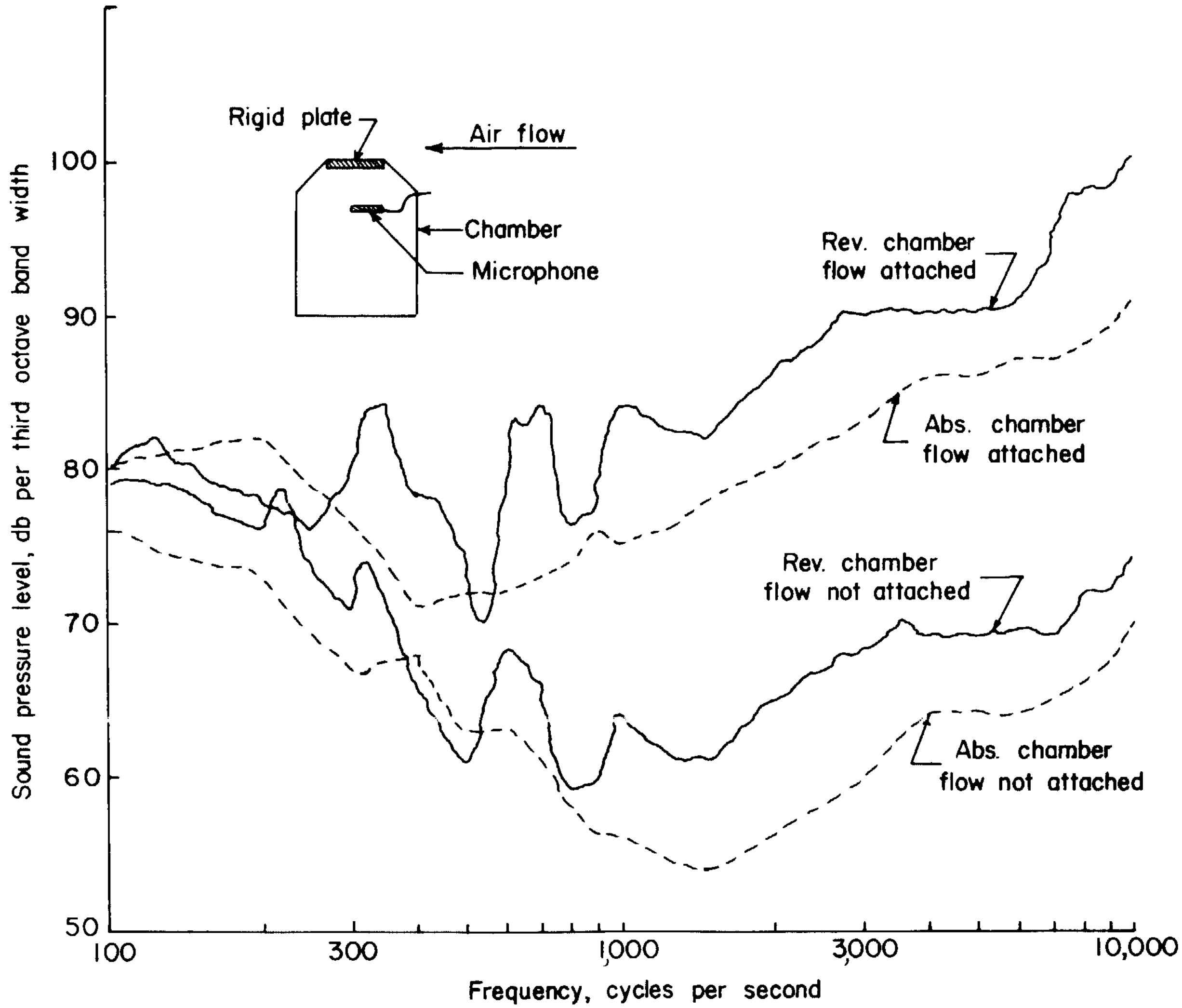

Figure 8.- Internal noise spectra of test chamber as measured with a rigid plate mounted in the test panel location.

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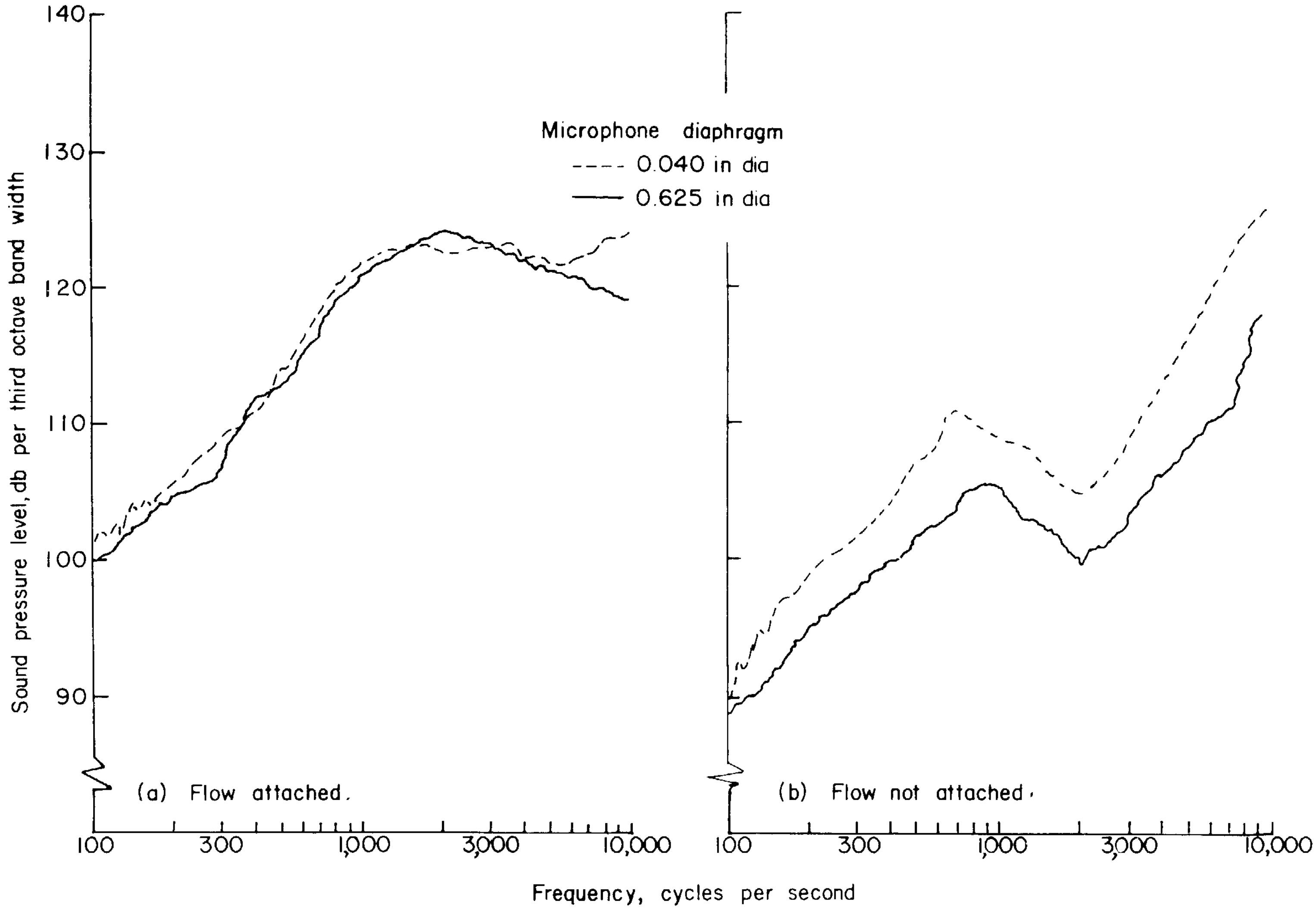

Figure 9.- Surface-pressure measurements on a rigid plate for two different microphone sizes.

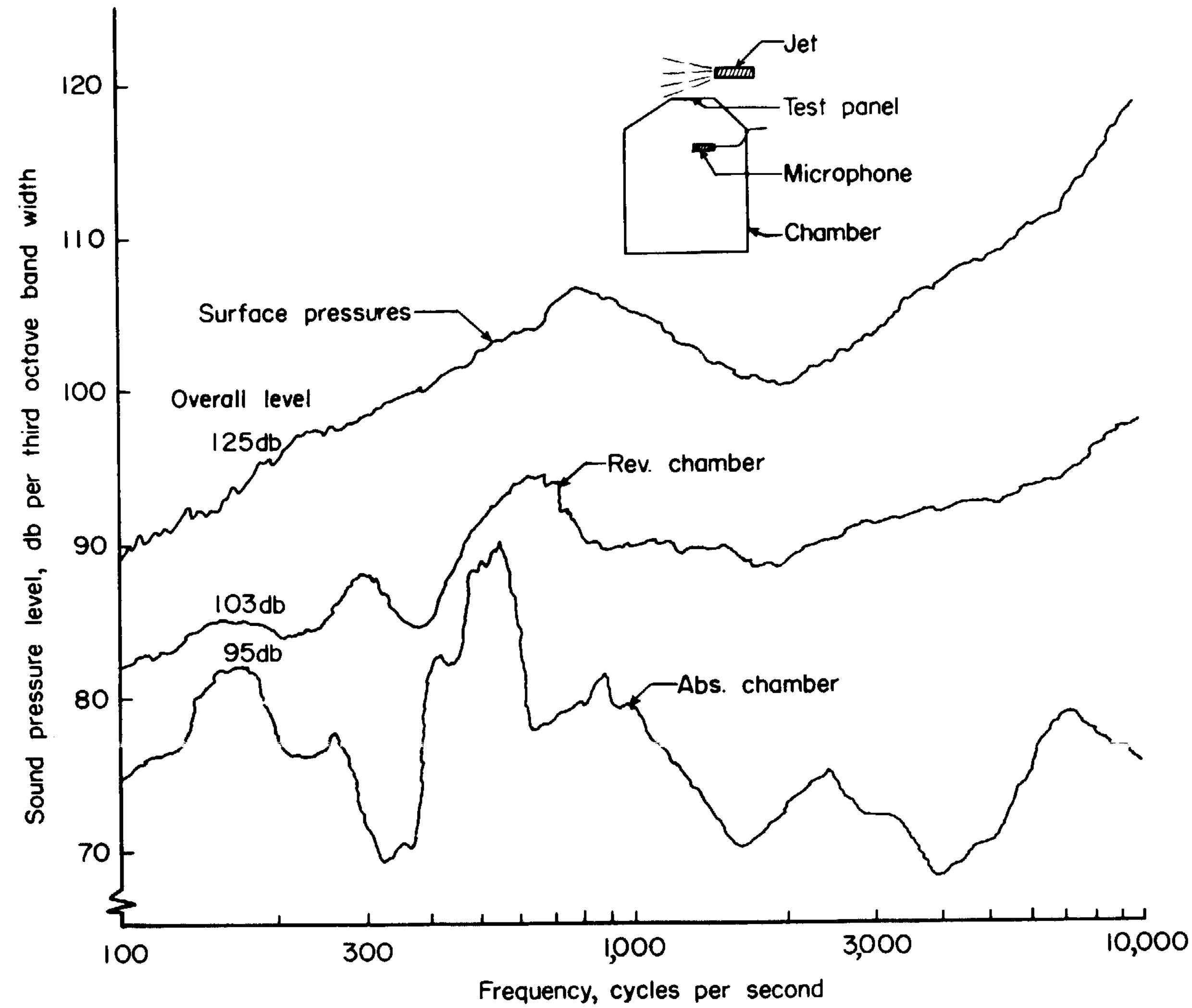

Figure 10.- Comparison of surface-pressure measurements with noise measurements inside the test chamber for the case where the flow is not attached to the test panel.

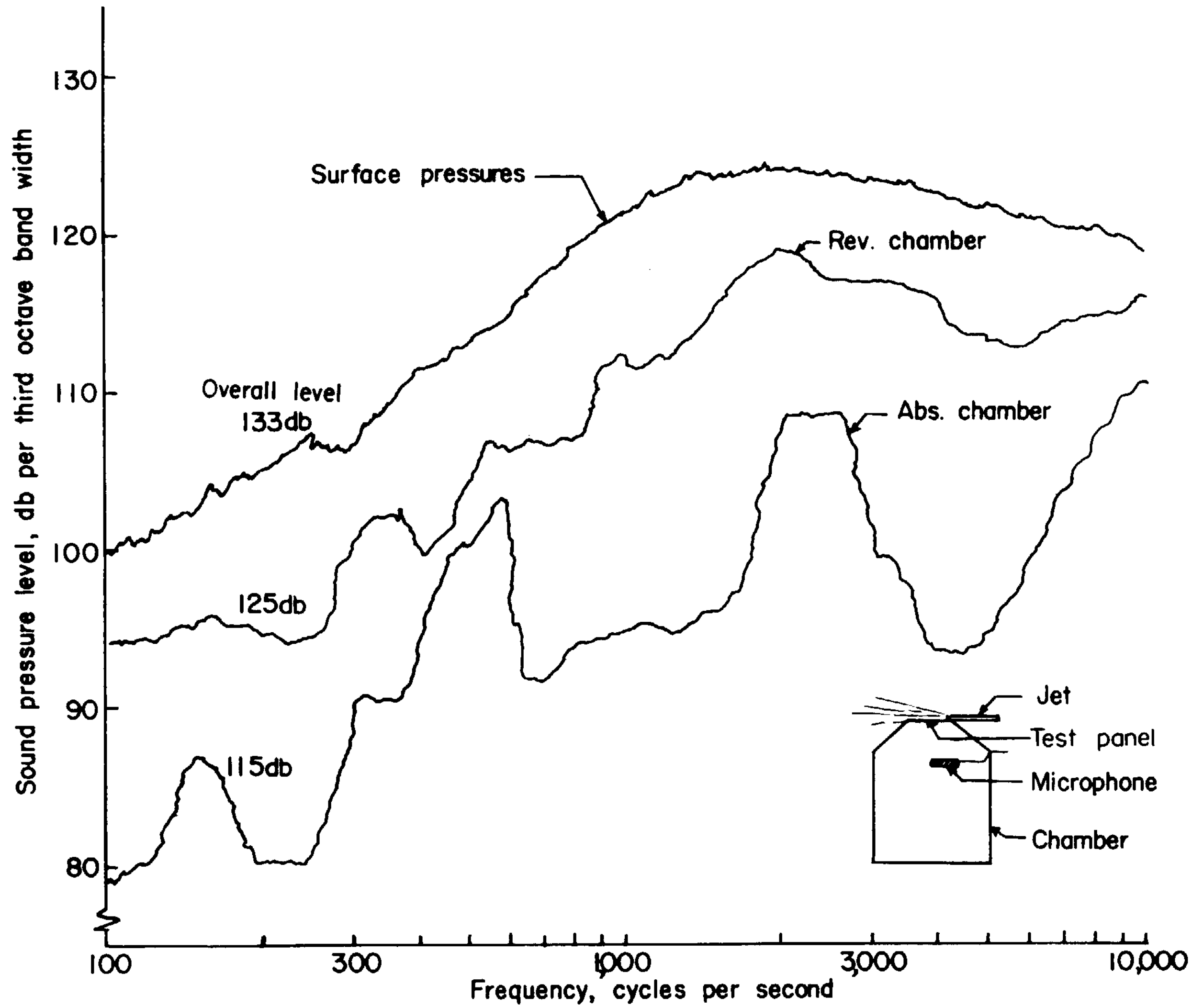

Figure 11.- Comparison of surface-pressure measurements with noise measurements inside the test chamber for the case where the flow is attached to the test panel.

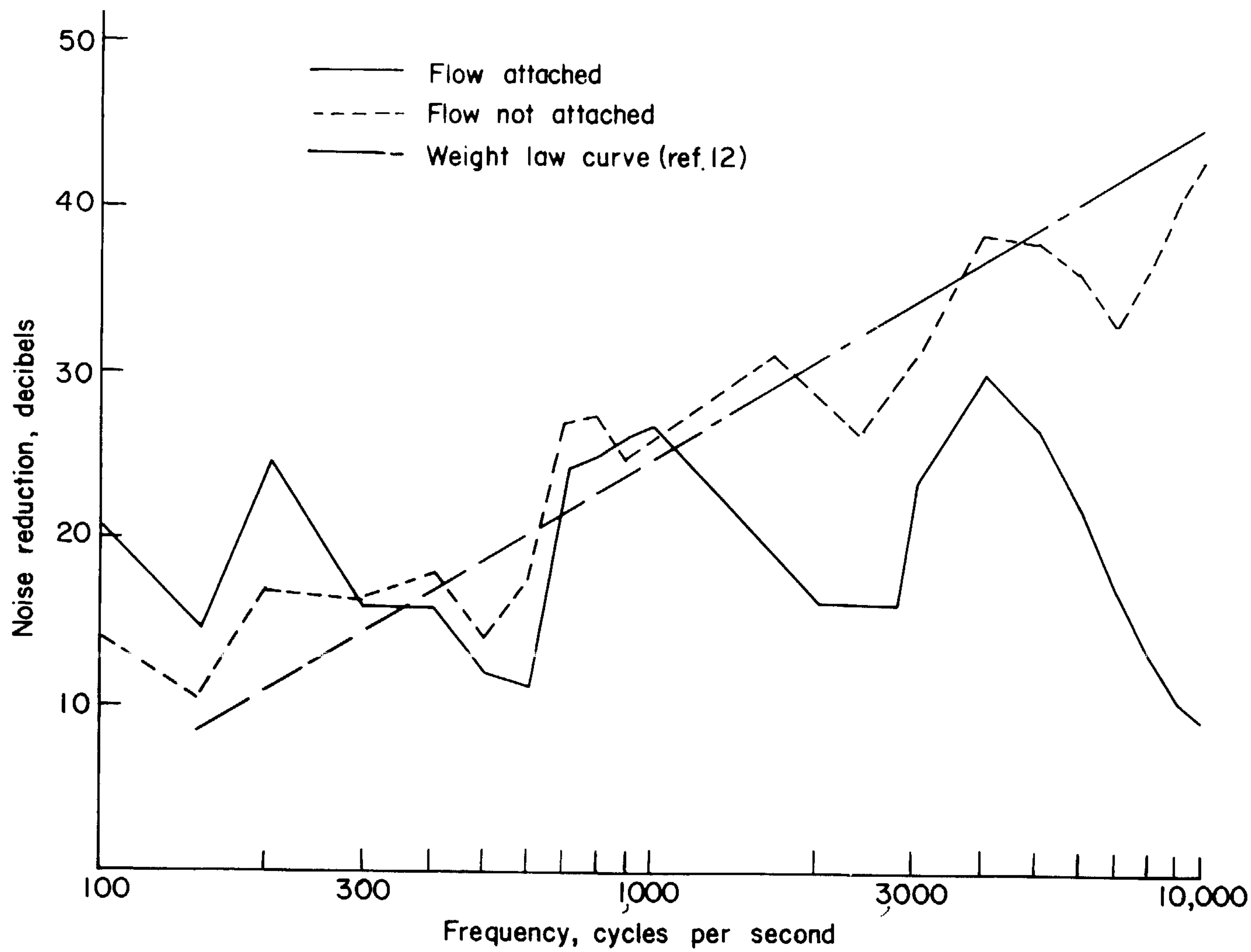

Figure 12.- Noise reduction through the test panel for an absorbent chamber as determined from data of figures 11 and 12.

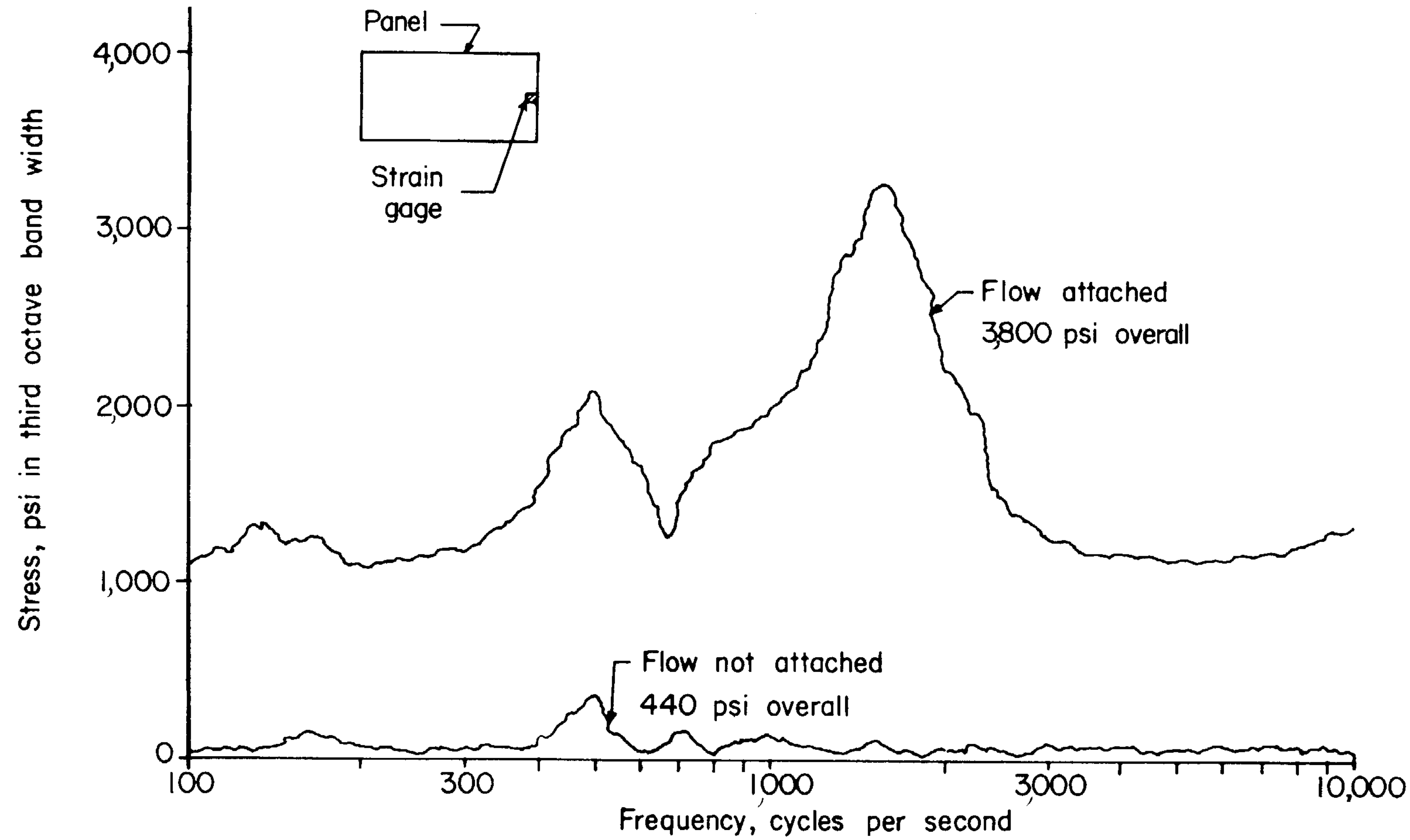

Figure 13.- Stress response of a 0.020-inch panel in combination with the reverberant chamber.

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