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INTRODUCTION

The response of aircraft or spacecraft structures to complex noise inputs involves such important variables as structural materials, fabrication techniques, and related environmental conditions. At the Langley Research Center we have a research effort underway which ranges in scope from the study of noise responses of simple panels to acoustic environmental studies of large and complex space payloads. The purpose of this paper is to present a status report on some of these current research studies.

The types of studies to be covered are indicated by the sketches in the first figure. The first part of the paper will deal with panel studies, and then brief discussions will be given of studies involving shell structures and full-scale payloads. The sketch in the upper left illustrates simple aluminum panels which are being studied to determine some effects of varying the panel curvature on panel dynamic response. The sketch at the center represents a visco-elastic panel on which fatigue studies are being made at elevated temperatures. On the right is illustrated a corrugation-stiffened panel incorporating a thermal expansion joint. The shell structure illustrated represents a 1/5-scale Saturn I "lox" tank. The studies to be described are part of a comprehensive program to evaluate the use of models in support of structurally scaled dynamic studies of the complete Saturn vehicle. Finally, a description will be given of a full-scale environmental test on a complete Agena instrument package as represented by the sketch in the lower right of the figure. For such complex structures as these, full-scale proof testing in a realistic environment is the only satisfactory approach currently available.

PANEL FATIGUE STUDIES

Studies of response of panels to noise have been conducted both in house and under contract in order to increase our knowledge of the dynamic behavior of some of the configurations being considered for application to high-performance flight vehicles.

Simple Curved Panels

Studies involving the effects of curvature were made for simple aluminum-alloy panels, as illustrated in figure 2. The panels were 20 inches by

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20 inches and of 0.020-inch-thick, 2024-T3 clad aluminum. They were attached to steel test fixtures with 3/16-inch-diameter aircraft bolts with washers, and were torqued to 25 inch-pounds. Distance from the center line of the bolt hole to the panel edge was 5/8 inch, and bolt spacing was $1\frac{1}{2}$ inches. With this method of attachment, the free or effective size of the panel was approximately 17.5 inches by 17.5 inches. Panels were instrumented with strain gages and, for random noise tests, were oriented relative to the air jet noise source as indicated in the figure. Tests have been made with radii of curvature of 4 feet, 8 feet, and infinity (flat panel). Response characteristics of the panels at these curvatures were determined by means of a discrete frequency noise source which could be operated in such a manner as to sweep through a range of frequencies.

Shown in figure 3 are the resulting root-mean-square bending strain responses plotted as a function of frequency for each of the three panel curvatures. The driving noise (normal impingement) was held at a constant 125 dB level while sweeping through the range of frequency. The characteristic flat panel response is illustrated in the bottom part of the figure. For the input noise level of the experiment, it can be seen that nonlinear effects are evident. A stiffening or hardening is seen to occur in the form of a rise in the response frequency as strain amplitude increases.

In the case of the 4-foot-radius curved panel a markedly different response pattern is obtained, as shown in the top of the figure. The strain levels are lower, there is relatively more response at the higher frequencies, and there is a trend toward a softening; that is, the response frequency tends to decrease with increasing strain amplitude. The 8-foot-radius panel exhibits response characteristics which are intermediate between those of the others and, at this particular input level, behaves essentially as a linear system.

Random noise tests in which a number of these panels were tested to failure were made in Langley's air jet facility, which is shown in the photograph of figure 4. The noise is the mixing noise of the air jet, and the view of the figure is looking upstream into the jet exit. Ahead of the exit are four 90° pipe bends which are useful for increasing the noise level and for shifting the noise energy in the low-frequency direction. Panel specimens are located parallel to the jet boundary in each of four positions around the jet exhaust. Overall sound pressure levels of up to 160 dB are obtained in this manner. Some of the results obtained with this setup are shown with the aid of the bar graph of figure 5, where the range of times to failure for a number of panels at each curvature are indicated. It is seen that an increase in the time to failure is associated with increased curvature. The failures obtained were skin cracks located along the edge of the washers (see fig. 2), and strain measurements were obtained near these failure locations. The curved panel strain data show a marked reduction in level compared with those for the flat panels. The fact that the curved panels did not exhibit much longer times to failure suggests that significantly different stress concentration factors may exist.

Figure 6 shows mean-square spectra of sound input and strain response for flat and 4-foot-radius curved panels. Sound pressure was measured at the

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reference point illustrated in the figure. Mean-square sound pressures per cps (estimated from measurements using a 25-cps bandwidth filter) are plotted versus frequency in the upper graph of the figure. The above analysis shows energy of the input to be concentrated largely at 100 cps. A spectrum of strain responses (estimated from measurements using a 25-cps bandwidth filter) is shown in the lower graph in the figure. Mean-square strain in microinches per inch per cps is plotted versus frequency for a flat panel and curved panel. The curves represent the sum of the edge bending and membrane strains at the gage location shown, which is the same as for the comparable discrete frequency data of figure 3. In both cases panel response was sharply tuned near 100 cps where the input spectrum peaked; however, the panel with greater curvature has a greater response at the higher frequencies. The flat panel (solid line) bending strain peaked at 100 cps, and the membrane strain peaked at twice the bending frequency. For the 4-foot radius of curvature panel the membrane response was low and lacked prominent peaks; thus the response spectrum of figure 6 is essentially the bending strain responses. A prominent peak is still shown between 100 and 125 cps.

Visco-Elastic Panels

Studies to determine some effects of combined elevated-temperature—intense-noise environments on fatigue of commercially available visco-elastic panels are underway under a contract with North American Aviation of Columbus, Ohio. Configurations for which some data have been obtained are illustrated schematically in figure 7. The panels are 24 inches square with two hat-shaped stringers riveted across the back side. These stringers were located 5 inches from the center line, thereby forming a 10-inch by 24-inch panel bay in the center. The visco-elastic panels were made up of two aluminum facing sheets of 0.016-inch thickness with a 0.017-inch thickness of visco-elastic material (trade name - Dyna-Damp) bonded between the sheets as illustrated. A control panel of 0.051-inch-thick aluminum was constructed and tested for use as a reference for comparing the results obtained with the visco-elastic panels. All aluminum used in these tests was 2024-T3 clad. The edges of the test panels were riveted to $1\frac{1}{2}$-inch channel frames which in turn were attached to the mounting frame of the acoustic test chamber. The tests were made in the grazing incidence test chamber of North American's discrete frequency siren facility. In the wall of this chamber the panels were mounted with the stiffeners running vertically on the panel surface away from the noise (fig. 7). In the opposite wall of the test chamber was a series of quartz tube heat lamps for heating the panels. The testing technique used was to sweep through a frequency range in the operation of the siren at the sound pressure level of the test. From this frequency sweep the fundamental resonant frequency of the panel center bay was determined from strain-gage measurements, and the tests were run at this frequency. Three control panel specimens and three visco-elastic panel specimens were tested at sound pressure levels of 148, 154, and 160 dB, both at room temperature and at 200° F.

Some results from these tests are shown in figure 8. Shown in this figure are the cycles to failure as a function of noise level in decibels. Failure was judged to have occurred when skin cracks were first visible. These cracks generally were detected near the rivet attachments of the center bay of the test specimens. The plot on the left shows results obtained at room temperature, and the plot on the right shows the results obtained at 200° F. The data points shown are the average of the data obtained on the three panels tested under each condition. These data show that the visco-elastic panels generally endure a larger number of cycles before failure is detected. This margin of improvement is greater for the room-temperature conditions than for the 200° F conditions. This result suggests that the visco-elastic material may be losing some of its effectiveness at the elevated temperature condition.

Corrugation-Stiffened Panels

The last panel study to be described is concerned with a structure designed for application as a hot structure for lifting reentry vehicles. The acoustic study was part of a Langley project to design and test such a structure under a variety of environmental conditions associated with reentry loads and elevated temperatures (see ref. 1). This acoustic study was made in the random noise environment of the Langley air jet facility.

The structure studied is illustrated in figure 9. As shown, the test panel structure is 12 inches wide by 48 inches long and forms the top surface of an 8-inch-deep box. The part of the structure which was studied in detail was an expansion joint which is illustrated by the inserted sketch. The material used was light-gage Inconel X, fabricated by a welding-riveting process. The top skin was bonded and stiffened by a corrugated under skin, welded to form a composite panel. Of special interest in these acoustic tests are the panel skin terminations at the expansion joint. The outer skin was terminated by a row of rivets at the expansion joint attachment. The inner skin was terminated by a Z-member which was spot welded to each of the corrugation flats. These spot welds were found to fail during acoustic fatigue tests, and outer skin surface cracks developed along the attachment rivet line. The effects of noise level and edge attachment detail on the growth of the outer skin crack are indicated in figure 10.

Shown in this figure are plots of crack length as a function of time in minutes. Data on the left are for sound pressure levels of 163 dB and 156 dB, and for the condition of an initial failure of the undersurface welds. It can be seen that the crack growth is markedly faster for the higher noise level condition. The experiment was repeated for the condition of a riveted instead of a welded Z-attachment of the internal structure in the region of initial failure. As a result of using rivets in this internal structure, the time to failure of the outer skin and the associated rate of crack growth were markedly reduced, as can be seen in the right-hand figure. A point to be made from these data is that the structural integrity of interior attachment points of this type of built-up panel construction can be very important in the time to failure of skin surfaces and also in the crack growth problem. It should also be mentioned that, although skin surfaces may be readily inspected, the inaccessible understructures may be an important inspection problem relating to the fatigue of the skin surfaces.

TANK VIBRATIONS

A comprehensive series of studies is underway at Langley to determine the feasibility of using dynamic models of launch vehicles to predict the vibration characteristics of full-scale vehicles. As part of this general study, a 1/5-scale model of one of the Saturn I "lox" tanks is being used for some special noise and vibration studies. One of the setups in use is illustrated in figure 11. Shown is an echo-free room equipped with an air jet noise generator and instrumentation for making accurate noise surveys under the controlled laboratory conditions. The fuel tank, which is 11 feet long by 14 inches in diameter, was supported at the base by a cable suspension system attached to the ceiling structure of the room. The tank is an aluminum shell having a wall thickness of approximately 0.020 inch, and with its attachment structure at the two ends is structurally scaled to accurately represent the full-scale vehicle.

The capability exists for the tank to be mechanically excited by an electric vibrator and then acoustically excited by the random noise of an air jet. Accelerometers were installed along the length of the tank, and a microphone array was used for noise measurements. This setup of figure 11 permits a study of the tank response to both mechanical and acoustical excitation and, in addition, provides a measure of its acoustic radiation under controlled conditions.

As an indication of the vibration response of structures of this type, two spectra obtained by William M. Thompson, Jr., of LRC are presented in figure 12. Acceleration responses for a location on the tank surface midway between its ends are shown as a function of frequency for both the empty condition and the full-of-fluid condition. For each condition the sinusoidal driving force of 1 pound was applied at one end and was varied slowly throughout the test range. The roll-off at high frequency is due to limitation of instrumentation. It can be seen that the tank exhibits a very complex vibration response, and a large number of vibration modes can be identified. For this particular model, the dominant modes happened to occur in the frequency range of conversational speech, and a voice input to the mechanical shaker was quite faithfully reproduced into audible signals by the tank. As a matter of information, the vibration response of the tank was not markedly different when filled with fluid, as can be seen in the right-hand graph. The peak acceleration amplitudes are approximately equal to those of the empty tank, and the most readily observed difference in tank response is the appearance of some clearly defined, low-frequency modes for the case where the tank is filled with fluid. Further experiments are planned in order to evaluate the structural and radiation damping and the manner in which the tank responds to a broad-band acoustic input.

ENVIRONMENTAL STUDIES OF AN INSTRUMENT PACKAGE

Acoustic environmental tests of an Agena instrument package have recently been made in the noise field of the Langley 9- by 6-Foot Thermal Structures Tunnel. The tests were made at the request of the Air Force and in association with Lockheed Aircraft of Sunnyvale, California. Figure 13 shows a photograph of the Agena forward equipment rack in testing position at the tunnel. The view is looking toward a 12-foot-diameter diffuser exit of the tunnel. The Agena model is cradled in a shock-mounting suspension onboard a trailer. In this position, the test specimen is located at the center-line elevation of the tunnel exhaust and only a few feet from the exhaust stream boundary. The Agena package was about 5 feet in diameter and about 5 feet long. The aft end was sealed off with a nonflight structure, and the fore end was equipped with a dummy nose cone. The package was of skin stringer construction with skin surfaces being beryllium. Tests were made in a random noise environment, and accelerometer measurements were taken on structural members throughout the model.

Representative results from these studies are included in figure 14. At the top of the figure is shown the acoustic input in one-third octave levels. At the bottom of the figure are shown the resulting accelerations in one-third octave bands measured at two locations in the model. The acoustic input is noted to have a flat spectrum within about 5 dB from 100 cps to 10,000 cps. The acceleration responses, on the other hand, are noted to increase with increasing frequency up to about 2,000 cps which is approaching the useful upper limit of frequency of the accelerometer equipment. The accelerations of the shell structure were noted to peak at about 30g, whereas the peak accelerations measured on the more massive gyro guidance equipment are markedly lower, as would be expected, and in this case did not exceed about 6g. Such experiments as these are frequently required for complex structures designed for specific acceleration tolerances since at present there are no acceptable analytical means for accomplishing this task. It is hoped that basic information such as is presented here will be useful in the formulation of acceptable prediction schemes for future vehicles.

CONCLUDING REMARKS

A brief status report has been given on current studies of the dynamic responses of panel shells and complete equipment packages to acoustic inputs. The objectives of these various studies are to provide information for improving existing fabrication techniques of flight structures exposed to noise loads and the development of criteria for the establishment of vibration and acoustic specifications for complex structures of flight vehicles.

REFERENCE

1. Pride, Richard A., Royster, Dick M., and Helms, Bobbie F.: Design, Tests, and Analysis of a Hot Structure for Lifting Reentry Vehicles. NASA TN D-2186, 1964.

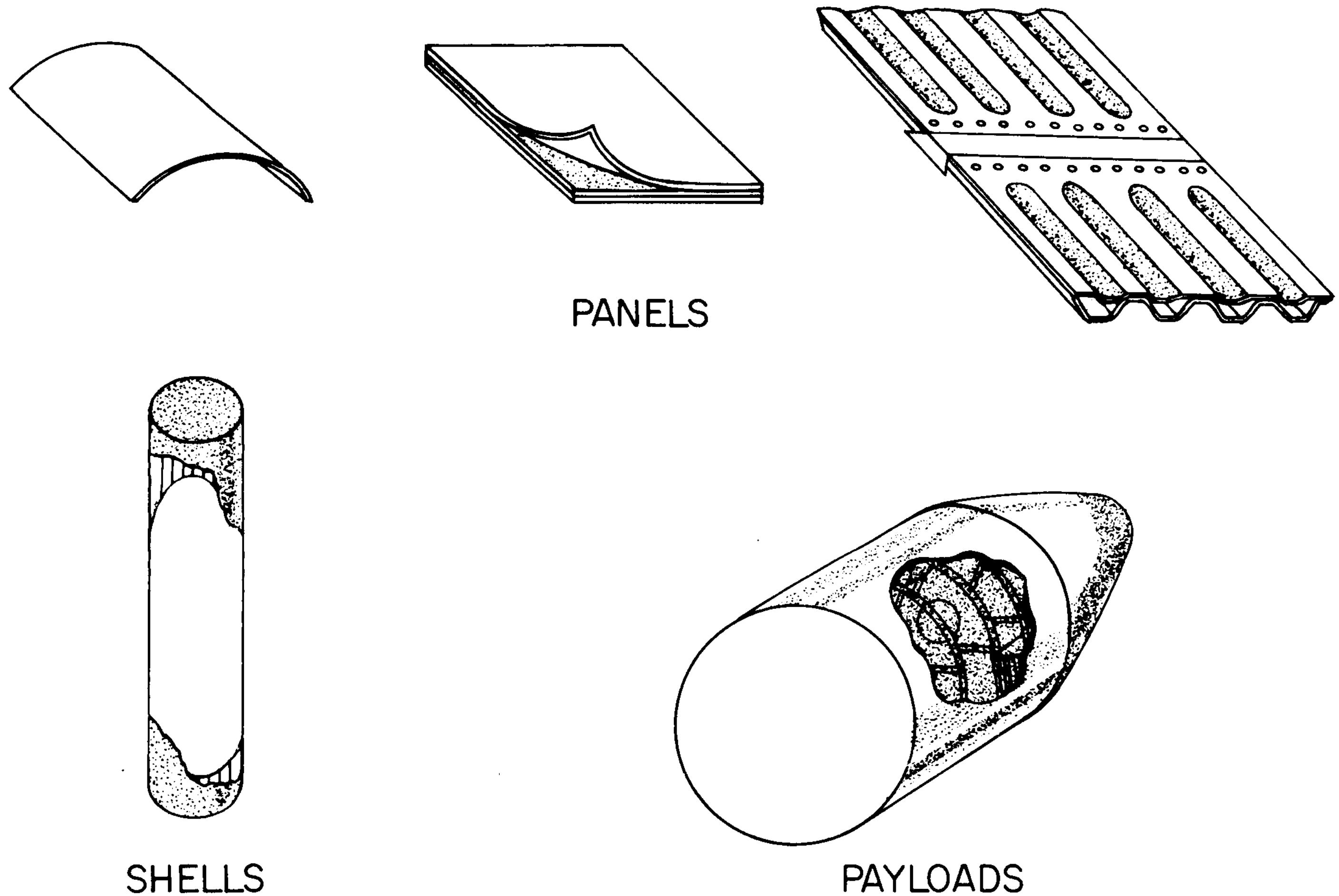

Figure 1.- Models for structural response-to-noise studies.

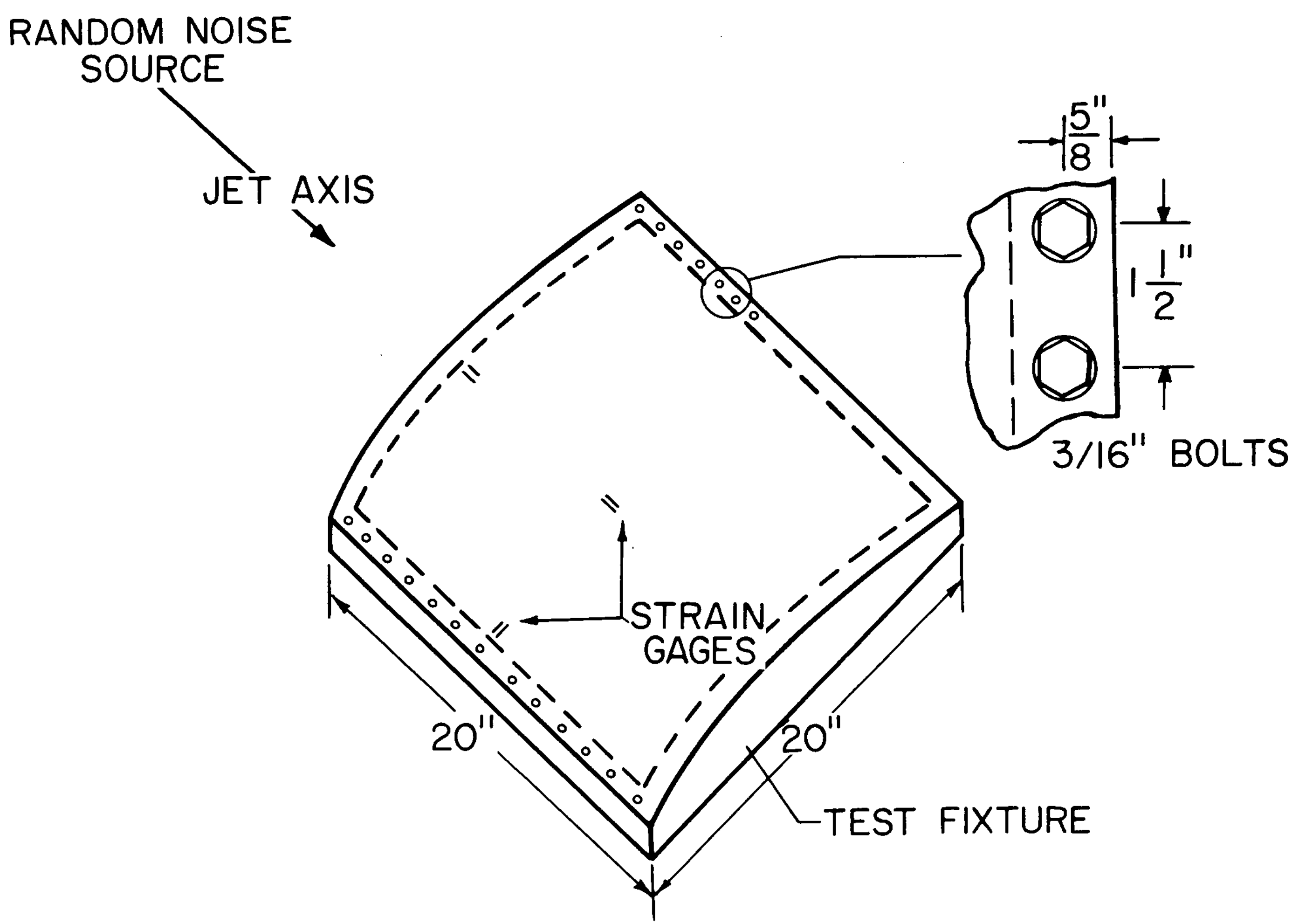

Figure 2.- Configuration for acoustic tests on 2024-T3 clad aluminum panels of 0.020-inch thickness.

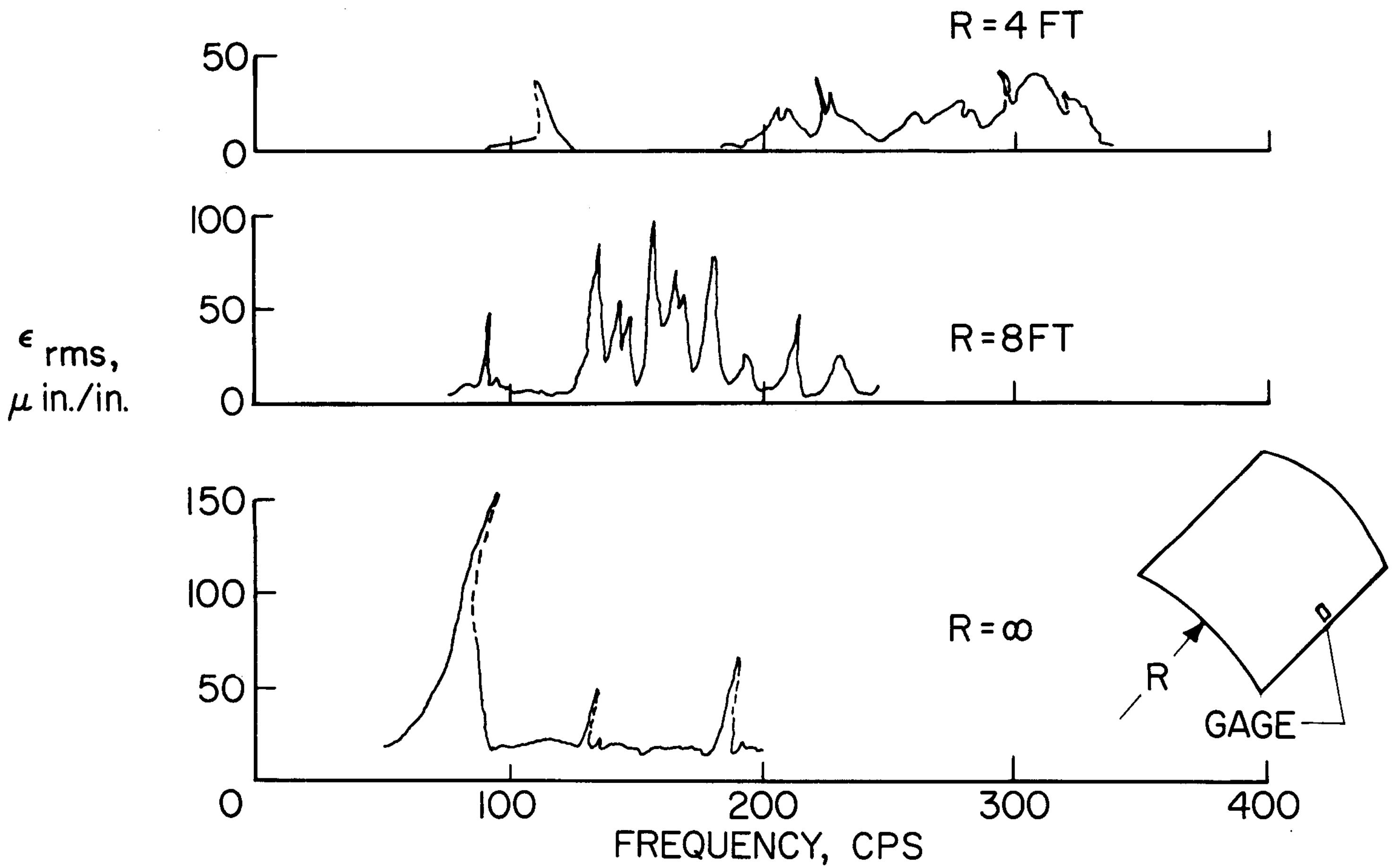

Figure 3.- Strain response as a function of frequency for 0.020-inch-thick panels of three different curvatures exposed to discrete frequency noise having a sound pressure level of 125 db.

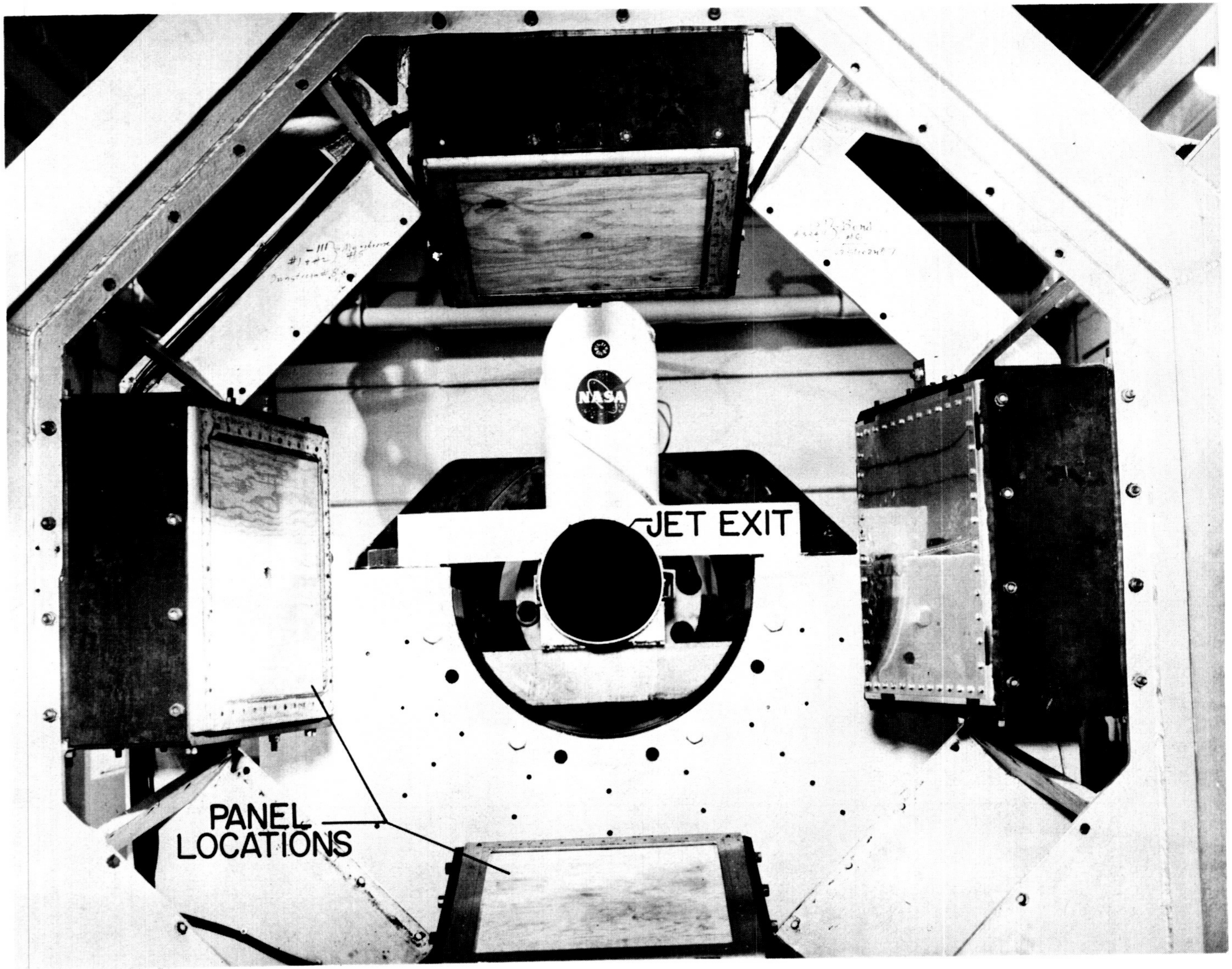

Figure 4.- Setup for random noise acoustic tests of curved panels.

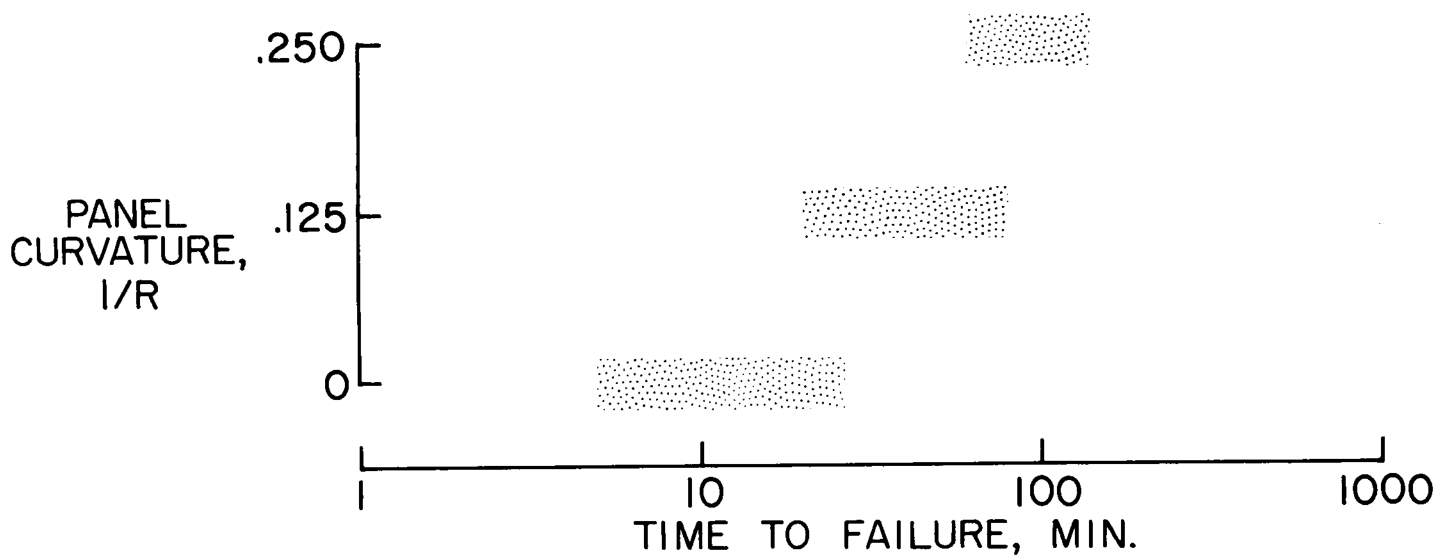

Figure 5.- Times to failure for 0.020-inch-thick panels of three different radii of curvature exposed to random noise.

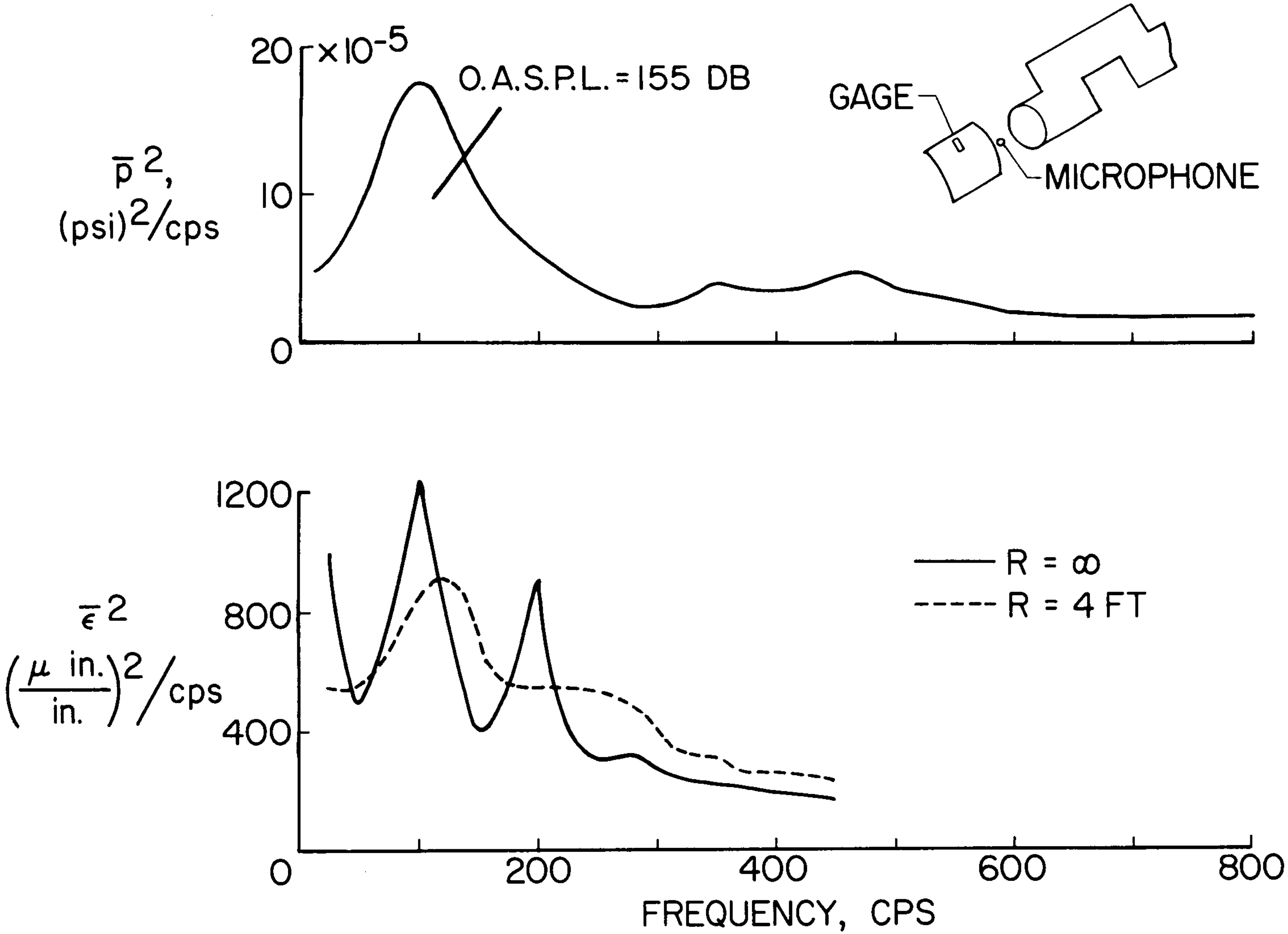

Figure 6.- Mean-square spectra of sound pressure input and strain output for aluminum panels exposed to random noise.

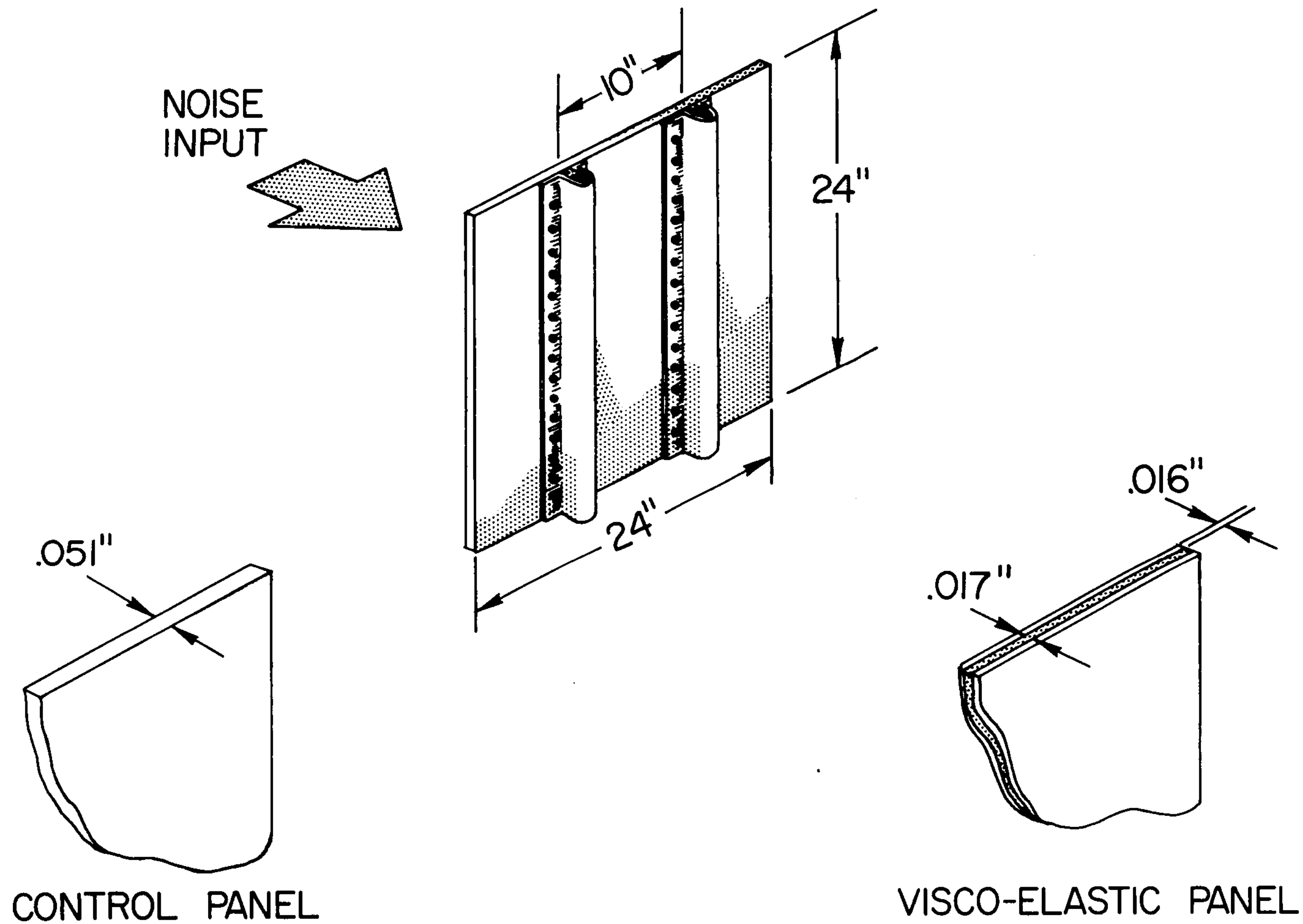

Figure 7.- Visco-elastic panel test configurations.

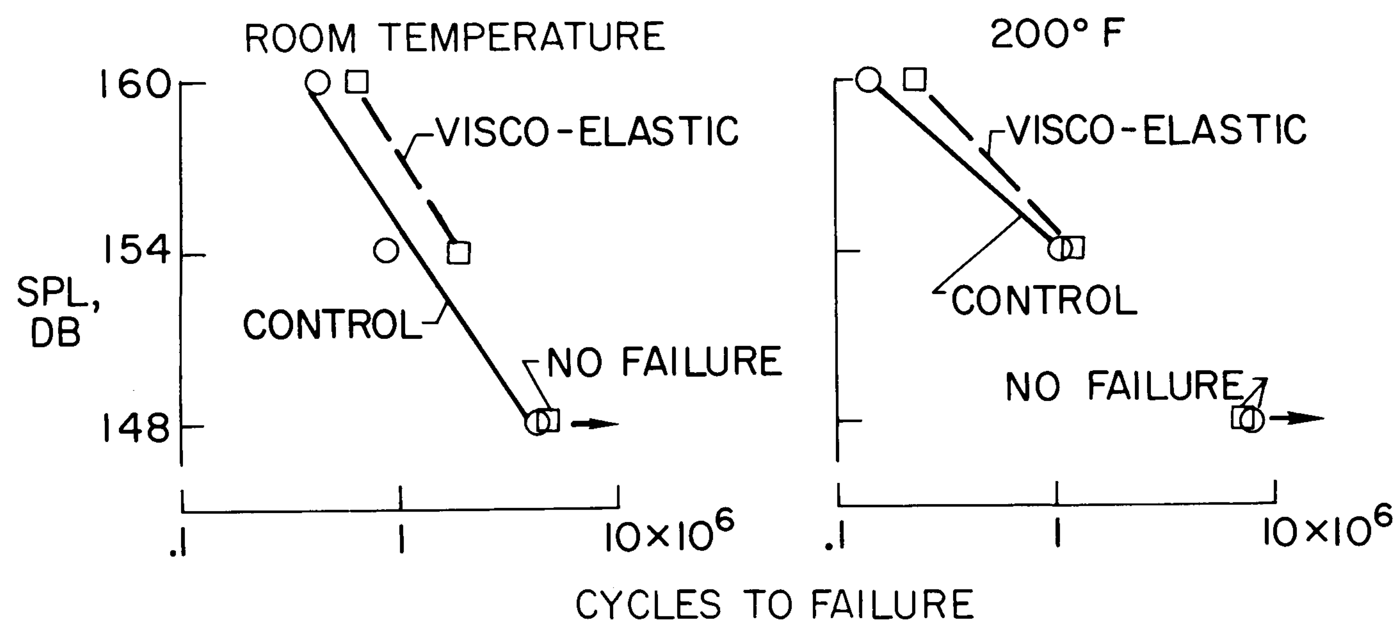

Figure 8.- Cycles to acoustic failure for visco-elastic and simple aluminum control panels at room and elevated temperature.

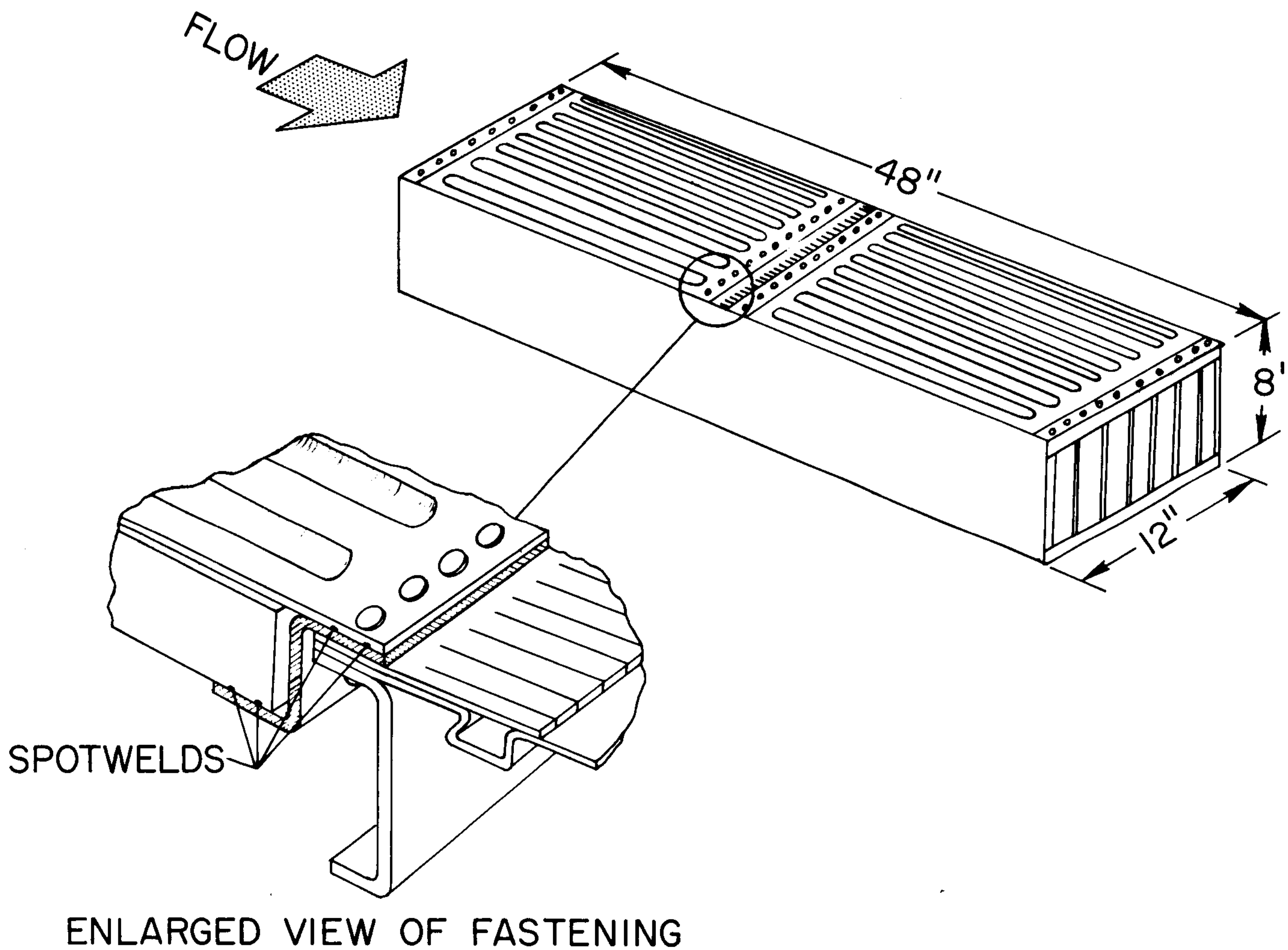

Figure 9.- Test configuration of corrugated skin panel.

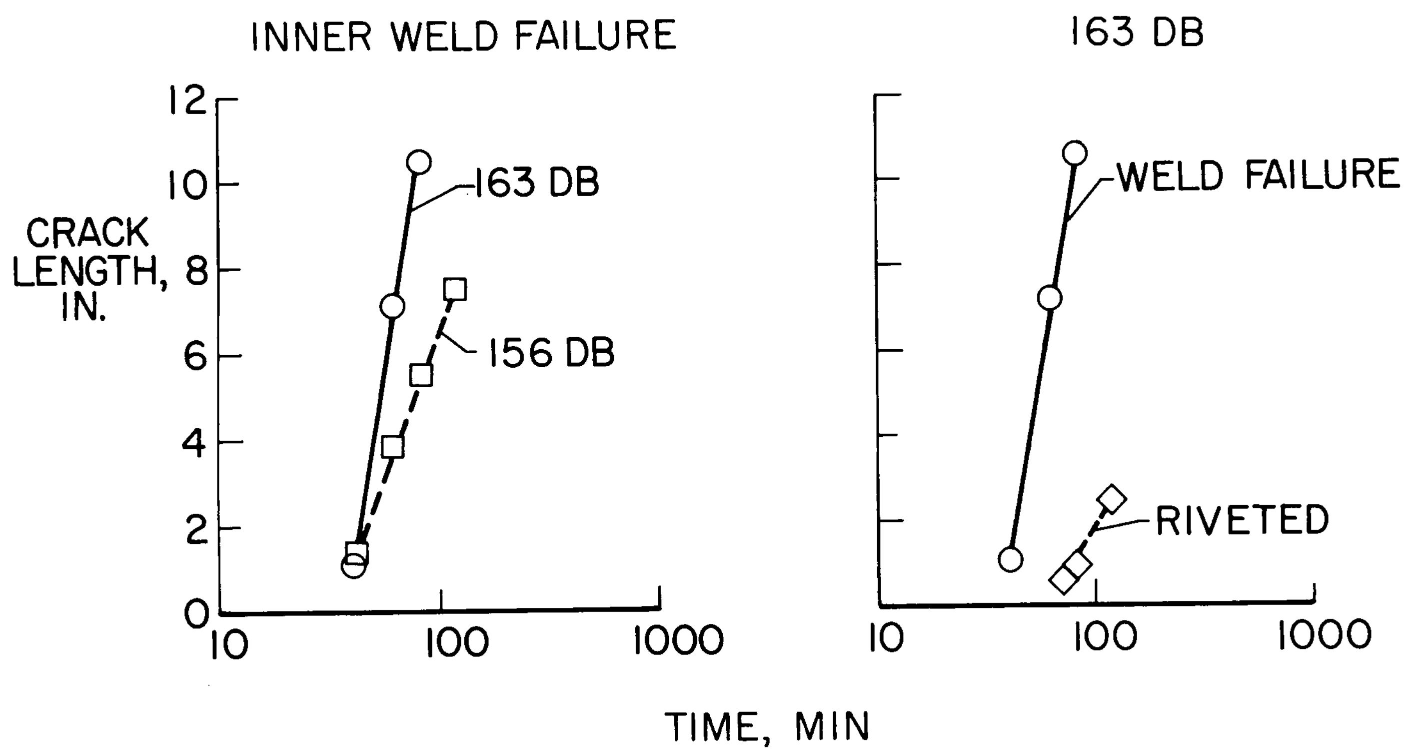

Figure 10.- Crack length as a function of time for two noise levels of excitation and for two configurations of panel internal attachment detail.

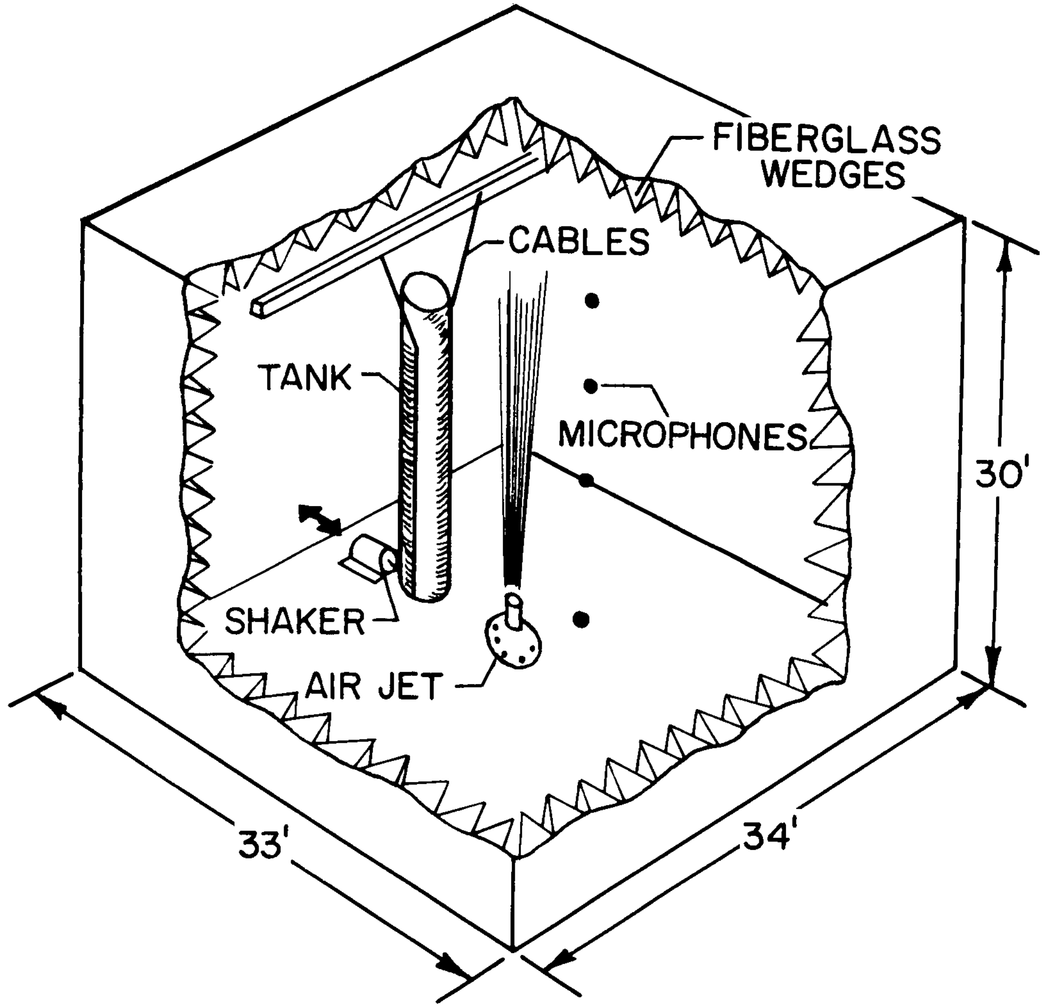

Figure 11.- Acoustic test chamber for missile fuel tank
response studies.

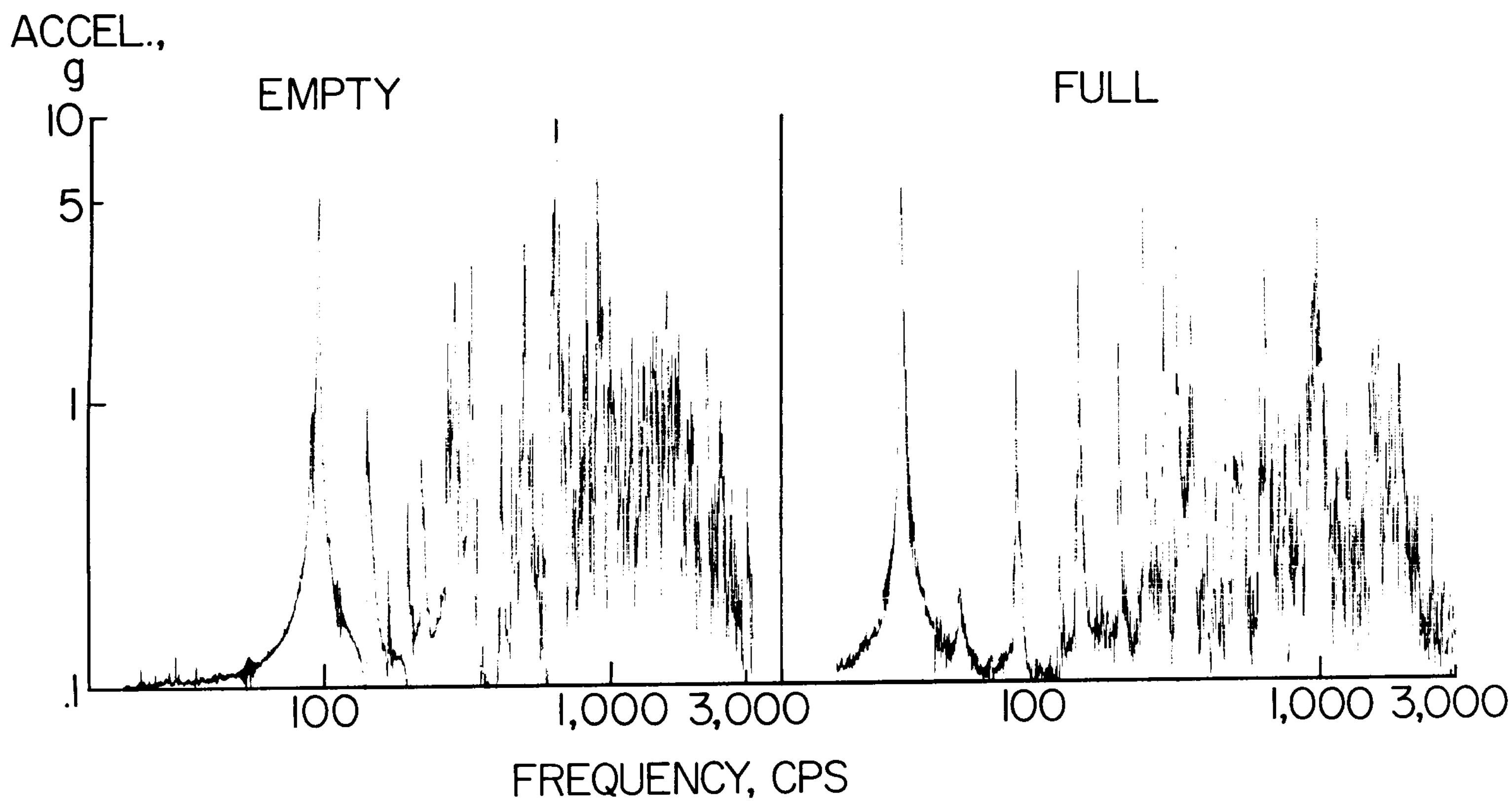

Figure 12.- Response of 1/5-scale Saturn with and without fuel.

Figure 13.- Agena forward equipment rack in acoustic testing position in the noise field of the Langley 9- by 6-Foot Thermal Structures Tunnel.

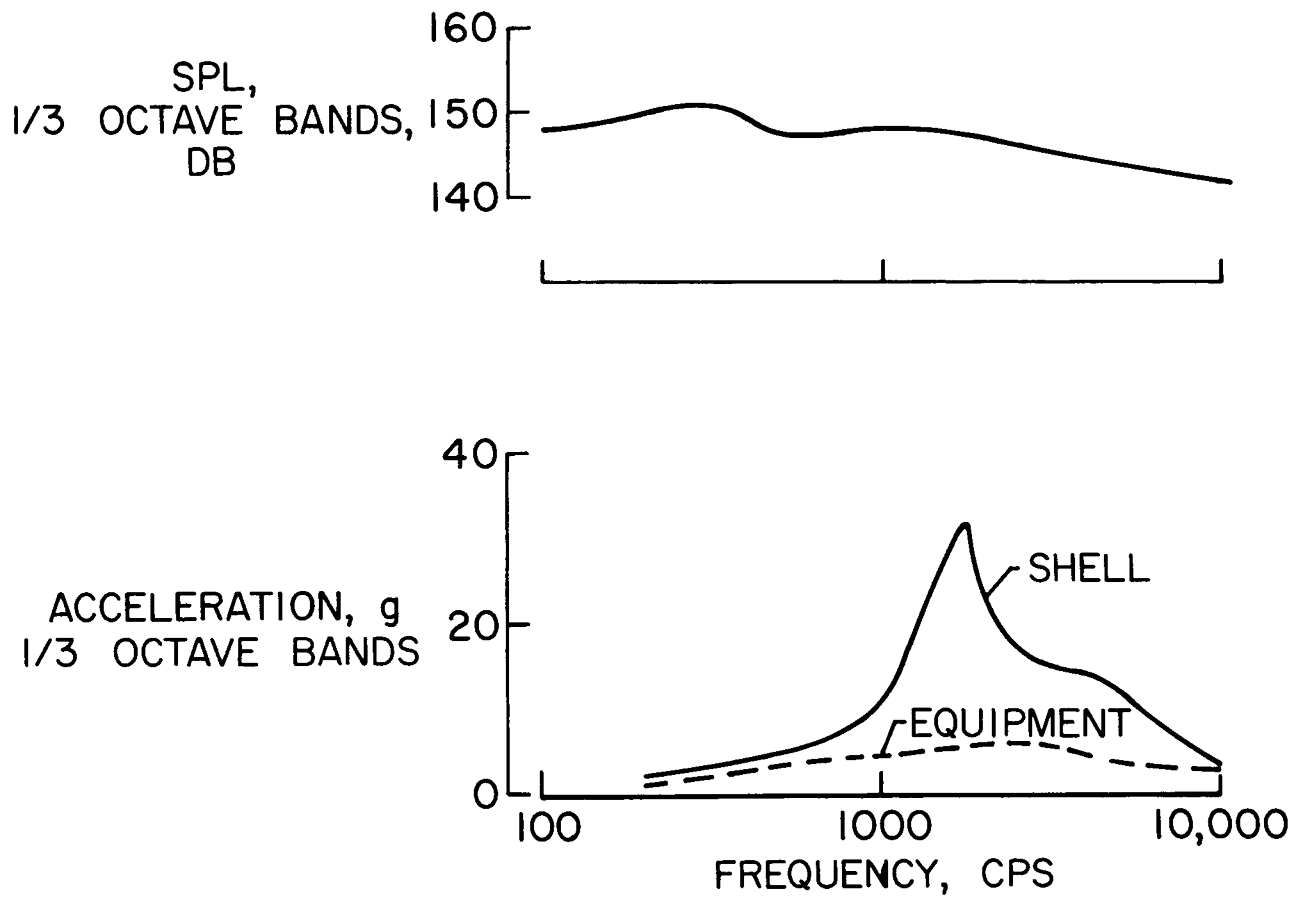

Figure 14.- Acceleration responses measured during acoustic tests of the Agena forward equipment rack.

NASA-Langley, 1964