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DESCRIPTION AND RESEARCH CAPABILITIES OF THE  
LANGLEY LOW-FREQUENCY NOISE FACILITY

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ABSTRACT

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In response to a need for research to determine possible effects of low-frequency noise associated with the launching of large spacecraft, the Langley Research Center has constructed an acoustic facility to operate in the frequency range from 1 to 50 cps. This facility makes use of a large, hydraulically driven speaker to generate sound-pressure levels of the order of 160 dB in a chamber of sufficient size to environmentally test full-scale manned spacecraft. This paper contains brief discussions of some low-frequency noise research problems, the overall design features of the facility, its operating characteristics, and its research capabilities.

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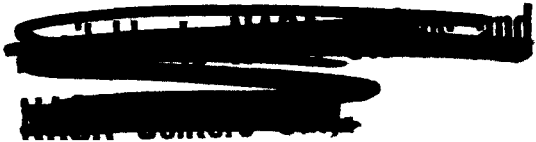
INTRODUCTION

The Langley Low-Frequency Noise Facility (LFNF) has been built to generate intense noise for large-scale environmental testing in the frequency range from 1 to 50 cps. Environmental testing in this low-frequency range is important in noise-induced problems associated with the launch environments of vehicles in the multimillion-pound-thrust range (ref. 1).

A characteristic of noise generated by rocket-powered launch vehicles is illustrated in figure 1 (from ref. 1). Shown is the variation of predominant frequency of the booster lift-off noise as a function of thrust. The frequency shown is defined as the frequency of the spectrum peak (see small sketch). The variation shows that for launch vehicles above one-half million pounds of thrust, the predominant frequency is below 50 cps, with multimillion-pound-thrust vehicles having high acoustic levels in the subaudible frequency range of below 20 cps.

In this low-frequency range there is little experience with acoustic environments, and the concern is for effects of this environment on flight structures and systems, buildings, and humans. Effects on both flight and building structures relate to structural response, structural integrity, and acoustic transmission as it affects the internal environment. Of special concern is the presence of acoustic inputs below the fundamental vibration frequencies of the structure.

Flight systems and similar equipment at the launch complex must withstand the direct acoustic loads and the associated acoustic-induced vibrations without the risk of malfunction or loss in reliability of performance. Also,



assurance must be obtained that man himself can take intense noise in this low-frequency range. Here the concern must go beyond the interest in hearing functions and in the ear alone. The concern is for the well-being of man's entire body, his ability to perform tasks, and his psychological sensations.

The LFNF has unique capabilities for acoustic environmental studies in the near-subaudible and subaudible frequencies. There also exists the capability for studies relating to noise transmission and propagation and for simulation of the sonic boom. The purpose of this paper is to describe the facility, to indicate its noise generating and testing capabilities, and to discuss its research applications.

### DESCRIPTION OF THE LOW-FREQUENCY NOISE FACILITY

The LFNF is shown in the photograph of figure 2, and some of the primary components are illustrated in the sketch of figure 3. The main features of this facility are a cylindrical test chamber, a large speaker in one end of the chamber, and a movable wall which can be positioned to close the opposite end of the test chamber. The facility may be operated with the chamber open, as shown in figure 2, or with the chamber closed (fig. 3) by the movable wall being positioned to tune the chamber. The speaker is hydraulically driven as a piston to generate sound pressures in the testing chamber. The facility is of sufficient size to accommodate a small building structure or a space vehicle of the Apollo command-module class. The testing chamber is man-rated so that complete manned vehicles may be tested.

The overall dimensions of the facility are 30 feet long by 27 feet in diameter. Along one side of the facility is a 10-foot by 30-foot building which houses hydraulic-system equipment on the first floor and a control room on the second floor.

The cylindrical test chamber was designed to obtain a relatively stiff structure with the natural frequencies above the top operating frequency of 50 cps. Analytical and model studies conducted in support of this design effort are reported in reference 2. The cylinder was fabricated of 1-inch steel, rolled and welded to form a continuous shell structure, and was stiffened by 18-inch T-rings of 1-inch steel on 48-inch spacings along its length. Longerons of similar construction were welded between the rings on spacings of 24" around the cylinder.

The movable wall is also of heavy steel construction. This wall is installed on railroad-type tracks and, in addition to counterweighting, has locking devices to prevent tipping or moving from a locked position. Movement of the wall, which weighs 26 tons, is accomplished by a cable system operated from an air winch. The wall is equipped with a pneumatic seal for use in closed chamber testing.

The 14-foot-diameter speaker is of aluminum honeycomb construction. As with the cylinder walls, the speaker was designed for high stiffness with frequencies above the facility operating frequency. The speaker shape is a double

cone with a depth through the center of 2 feet. The core consists of a 3-pound-per-cubic-foot honeycomb, and the 0.040-inch skin was autoclave bonded to the core. In addition to a requirement for high stiffness, it was necessary that the speaker weight be kept low so as to minimize inertia forces during operation of the facility. In the development of this speaker, a series of model studies was made, and information from these studies is presented in reference 3. The operation of the speaker is that of a piston being driven by a hydraulic driver, and the perimeter of the speaker is equipped with an adjustable Teflon seal which provides close clearance (within 1/16 inch) with the adjacent Teflon wall surfaces.

The electrohydraulic system used to drive the speaker is illustrated in the block diagram of figure 4. The main component of the hydraulic driver is a piston of an 8-square-inch area and has a maximum rated stroke of 9 inches. The hydraulic pressure (maximum of 3500 psi) is electronically controlled by a system where the desired acoustic environment is obtained by putting the necessary electric inputs into the system with a function generator such as a discrete-frequency oscillator, the playback of a random signal recorded on tape, the momentary closing of contacts, etc. This signal is then conditioned and fed into a computer circuit which forms part of a servo-loop circuit controlling the operation of hydraulic valving at the driver. The hydraulic system thus operates on command of the electronic circuit. In this manner, desired acoustic output environments such as sinusoidal, random, or impulse types having the N-wave pressure-signature characteristic of sonic-boom overpressures can be obtained.

This electrohydraulic driver system has limitations which confine the facility's operations to the range defined by figure 5. Essentially the operations are limited only by the 9-inch stroke of the driver until the frequency of 3.3 cps is reached. Above 3.3 cps there is a velocity limitation of 92 inches per second to a frequency of approximately 19 cps where the operation is limited by acceleration resulting from the inertial forces involved. It should be pointed out that the operational frequency ranges limited by amplitude and velocity are fixed; however, the acceleration boundary can be extended to higher amplitudes by operational techniques involving inertial balancing of the system with air springs in the chamber cylinder. The operational range shown in figure 5 was fully covered during evaluation tests of the facility.

In support of the development of the LFNF, theoretical analysis was undertaken to predict the sound-pressure levels that could be expected from this equipment. The theoretical methods used, along with experimental verification obtained with a 1/10-scale model, are described in reference 4. It is of interest to compare the predicted sound-pressure levels with those obtained in the test chamber during operations. Such a comparison for a sine-wave environment is shown in figure 7 for a normalized piston velocity of 1 inch/second. The measurements shown were taken with the tuning wall at a position such that the test chamber was less than 10 feet long. The microphone was located midway in the length of the chamber and 0.8 of the way to the chamber wall. Close agreement over most of the frequency range is obtained between the calculated and the measured sound pressures; however, at frequencies below 5 cps and above 30 cps, the measured values fall short of the calculated values. This disagreement at the low frequencies is attributed to leakage around the speaker

and movable wall. For these initial tests, this leakage was excessive because the speaker was operated without the peripheral seal. It is anticipated that adjustment of the recently installed Teflon seal will greatly improve the agreement obtained at these very low frequencies. With regard to the sound-pressure levels above 25 cps, the differences between the measured and the calculated levels are not fully understood; however, they can be partially explained by the effects of temperature variations, geometric details, and structural dynamic responses which were not fully accounted for in the calculations.

The acoustic capability measured during initial operation, along with the potential capability for the facility, are shown in figure 7. The capabilities indicated are for a sinusoidal environment for closed-chamber operation. The existing capability was measured during initial operations with no speaker seal installed. It is shown that levels above 160 dB were obtained at frequencies below 3 cps, with a dropoff in level to 140 dB at approximately 20 cps. Above 20 cps the movable wall provided tuning capability which resulted in levels of the order of 155 dB in the frequency range from 30 to 50 cps. In general, the existing acoustic levels are judged adequate for research programs of current concern.

The potential for higher acoustic levels is recognized, and techniques for obtaining additional capability have been considered in several studies. These studies indicate potential levels of 165 to 170 dB over the 1- to 50-cps operating frequency range. Consideration is being given to adjustment of the speaker seal, additional test-chamber tuning length, reduced chamber volume, and chamber-resonator devices. Analytical evaluations of these changes to the basic geometry are underway and are supported by model tests.

#### RESEARCH APPLICATIONS OF THE LFNF

The capability of the LFNF for experimental research is illustrated in figure 8. In the top of the figure is indicated the environmental capability of the facility, and at the bottom of the figure are indicated some of the things that can be exposed to the environments. The capability exists for studies of the effects of discrete-frequency, random, and impulse loadings on both building and flight-type structures. Large components or full-size structures can be accommodated in the 24-foot-diameter test chamber. The building structures may be occupied by people, and the flight structures may be manned and with onboard systems fully operational. Some of the specific research projects for this facility involve the response of building wall structures, the effects of noise on man, and means of simulating sonic-boom overpressures.

Studies relating to building wall response are concerned with simple wall structures of both plaster and dry-wall construction both with and without windows. Wall structures (8 feet high by 12 feet long) will be tested as one wall of a small test building having the other walls constructed to minimize acoustic transmission. The technique employed involves placing the test building in the chamber of the LFNF. The test program will include a range of sinusoidal, random, and impulse loadings.

## Tests of Man in Low-Frequency Noise

The first research study performed in the LFNF consisted of tests to determine possible effects of low-frequency noise on man. This study was carried out in close association with the NASA Manned Spacecraft Center and with the Aerospace Medical Research Laboratory of Wright-Patterson Air Force Base. The need for this research was associated with manned space flight where the concern is exposure to noise during launch lift-off and the maximum dynamic pressure phase of the atmospheric flight.

As shown in figure 9, previous laboratory experience in regard to whole-body exposure of man to low-frequency random noise was limited to levels well below those experienced with the ears alone. The tests in the LFNF raised the whole-body exposure by approximately 40 dB at frequencies below 10 cps and by 15 dB to 35 dB over the range of 10 to 50 cps. The tests were conducted using a team of five military subjects from the Aerospace Medical Research Laboratory. The subjects were tested two at a time with the other three serving as monitors. Exposure was limited to one-third octave bands and to durations of the order of 2 minutes each. Among the functions monitored were visual acuity, motor control, spatial orientation, cardiac rhythm, speed intelligibility, and tolerance.

In general, the results indicated that man can physically withstand low-frequency noise levels for the range of exposures studied; however, there were evidences of adverse effects such as annoyance and increases in task performance times. Detailed analyses of the medical findings have been accomplished by Dr. George Mohr and associates of AMRL (ref. 5).

## Applications to Sonic-Boom Research

Basic variables of sonic-boom signatures are indicated in the sketch at the top of figure 10 and include the overpressure ( $\Delta p$ ), the wave length ( $\Delta t$ ), the rise time ( $\tau$ ), and the impulse function (the positive impulse  $I_{pos}$  is illustrated by the shading). It is believed that all of these variables are important in the overall community-response problem. With regard to the response of buildings, the important variables are believed to be the overpressure, the wavelength, and the impulse (refs. 6, 7, and 8). It is significant to note that useful ranges of the above variables for N-wave type disturbances can be simulated by the facility. It is planned to make use of this particular facility capability for studying the response of structural components.

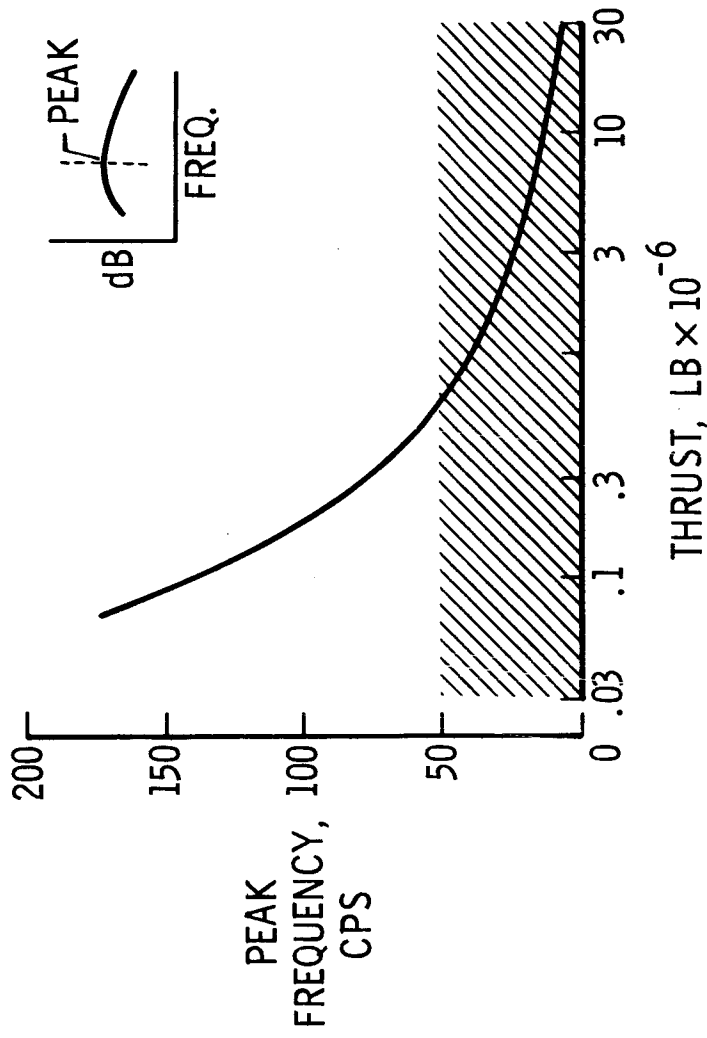
In figure 10, a sketch of the facility and a room-size test structure are illustrated. Also included is a sketch of a man to illustrate the relative size of the structure and to indicate the possible use of the facility for subjective-reaction studies. The test setup is such that the response of a single wall panel will be studied in detail. A variety of wall constructions, including several window and door installations, will be exposed to a wide range of N-wave type impulse loadings. Consideration is being given to subjective studies relating to the indoor sonic-boom exposure situation for which building vibrations are believed to be important.

## CONCLUDING REMARKS

Descriptions of Langley's new Low-Frequency Noise Facility and its operating characteristics have been presented. This new facility has important applications in studies related to the manned spacecraft program as well as possible applications in laboratory simulation of sonic booms associated with supersonic aerodynamic flight. Initial studies in the facility have provided information as to man's ability to withstand intense noise in the frequency range below 50 cps.

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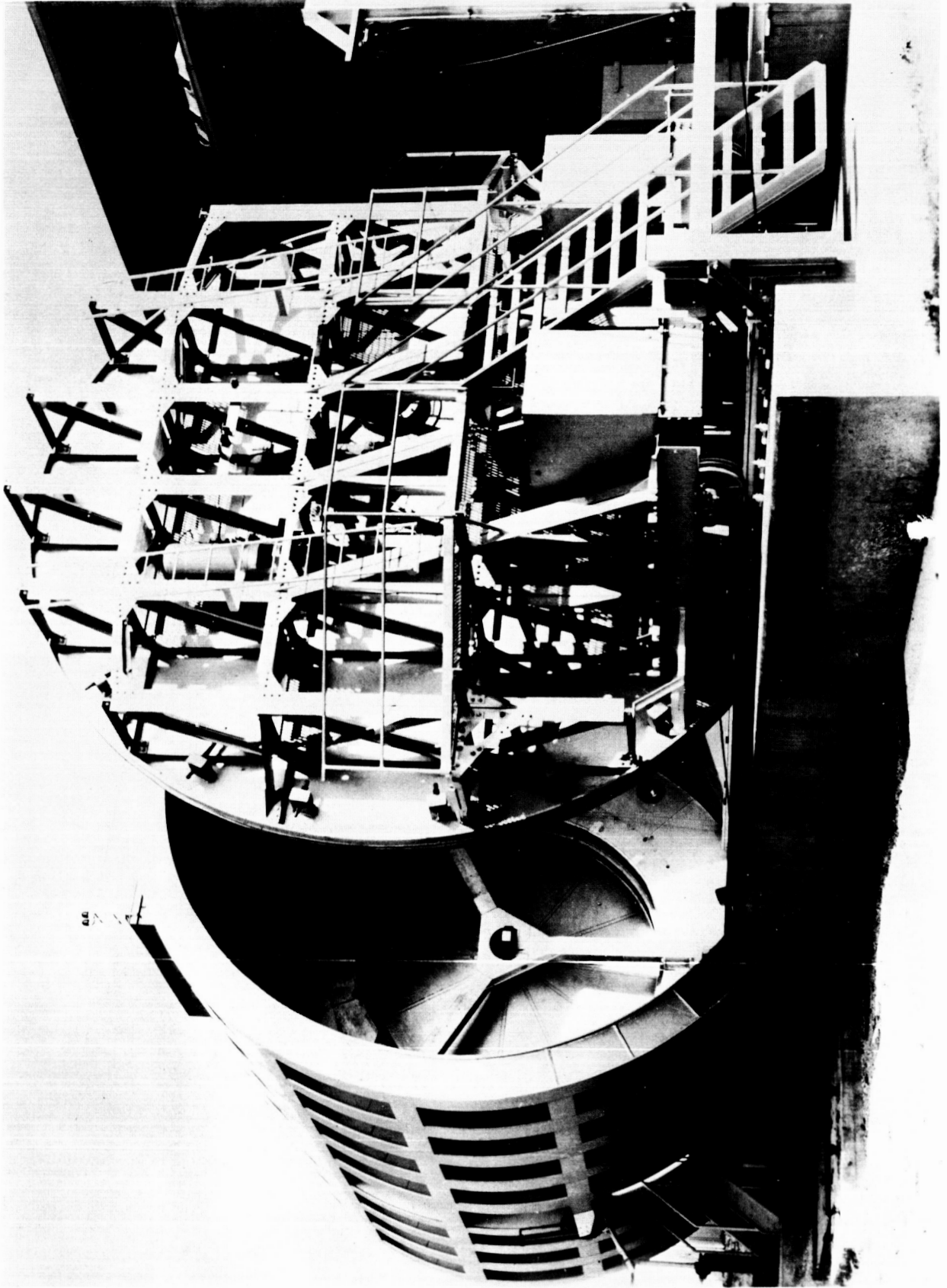
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Figure 1.- Variation of peak frequency of rocket launch-noise spectra with thrust.





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Figure 2.- Langley Low-Frequency Noise Facility.

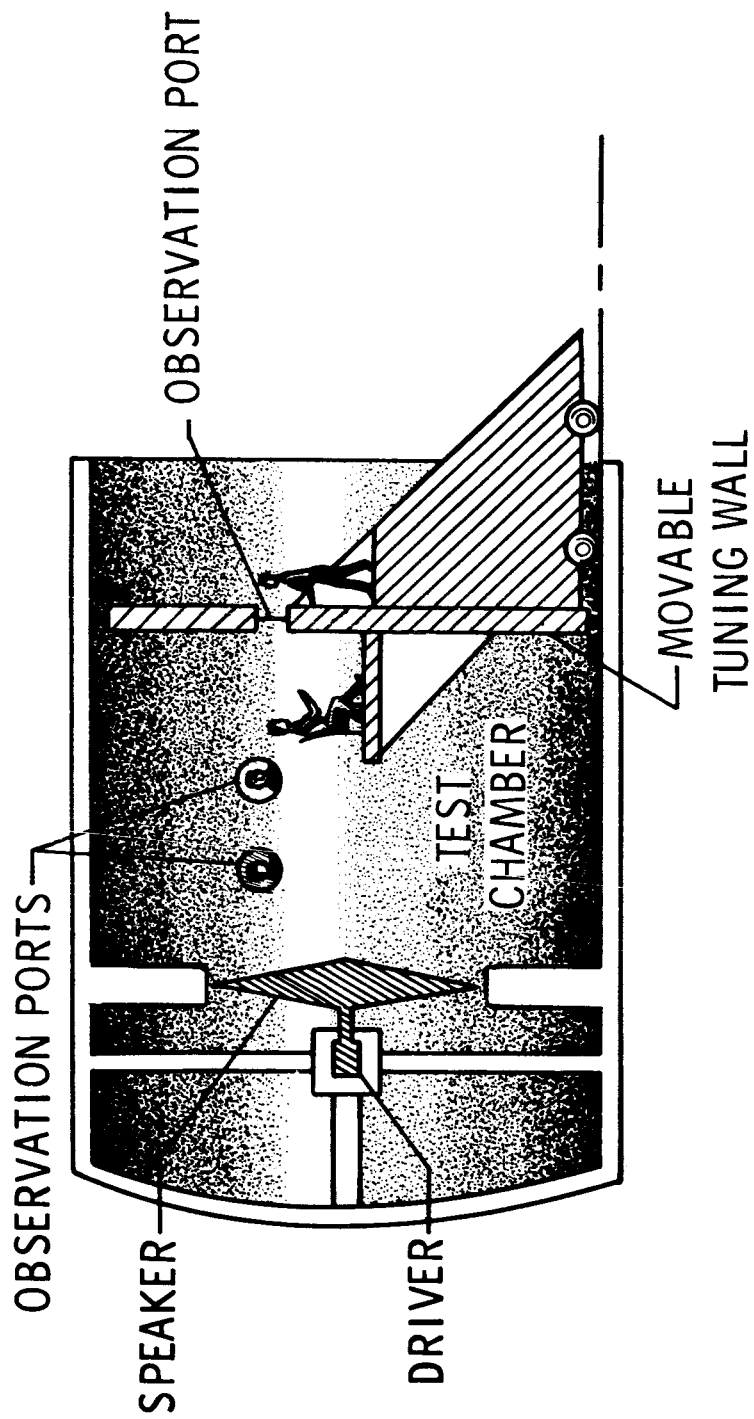


Figure 3.- Cross-sectional sketch of the Langley Low-Frequency Noise Facility.

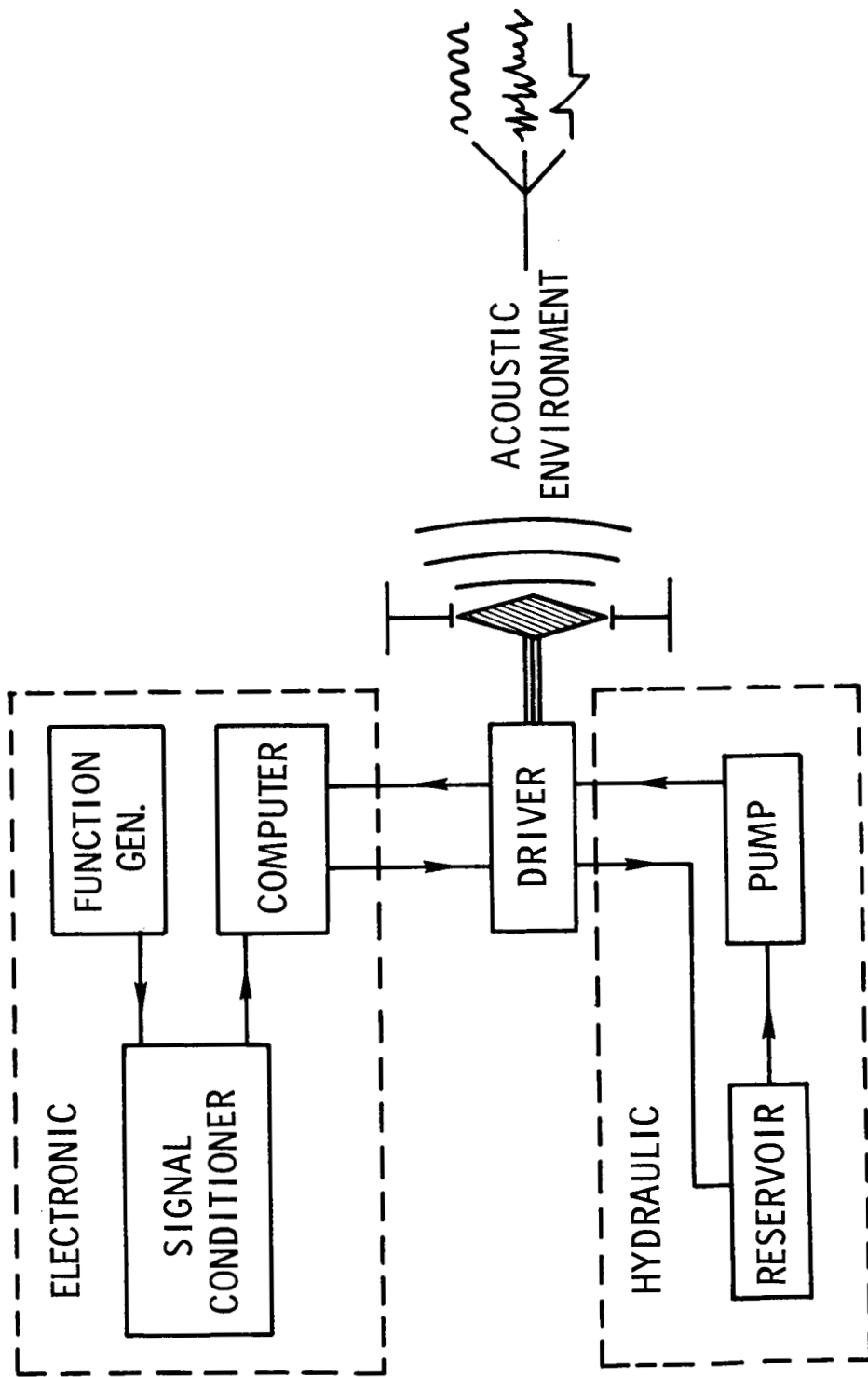
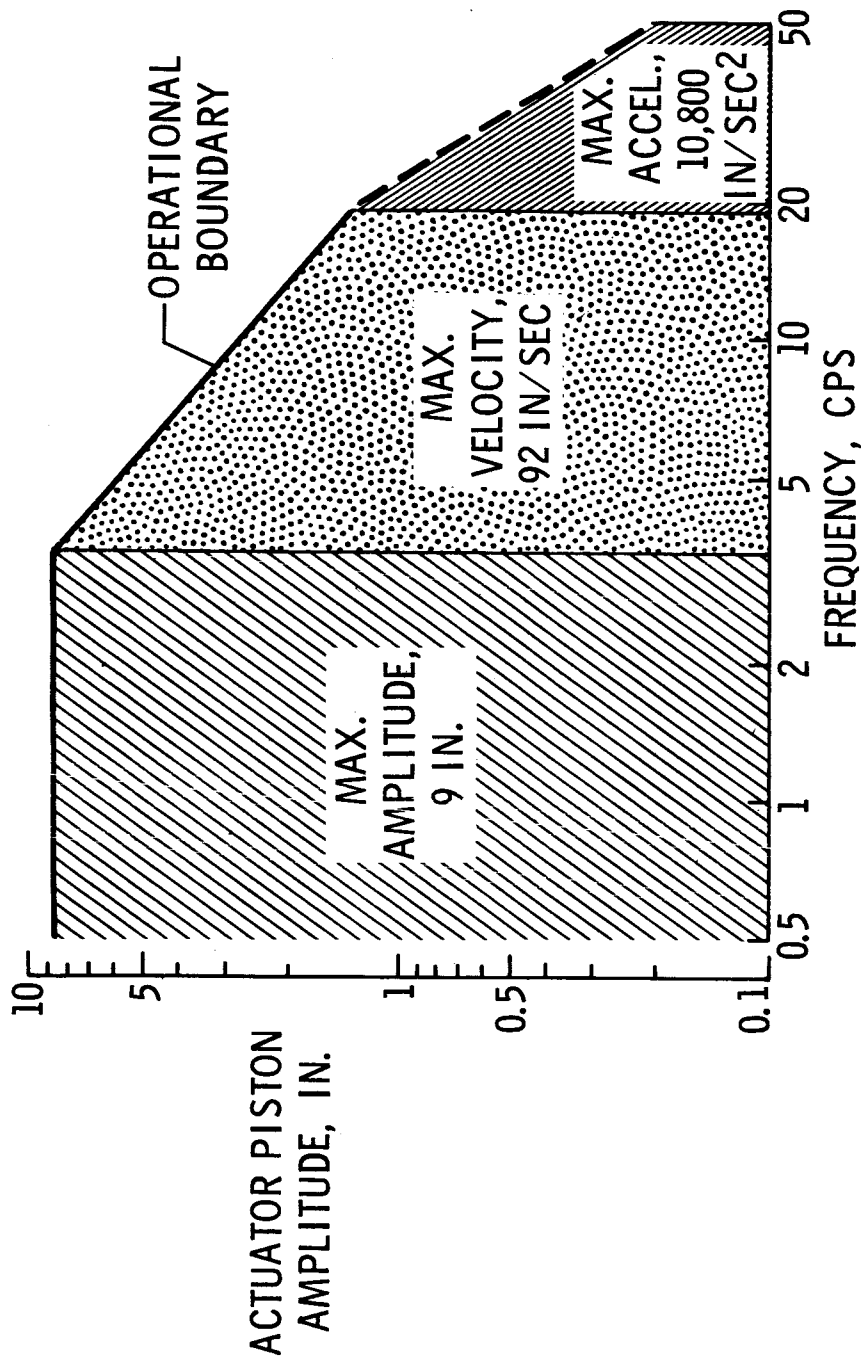
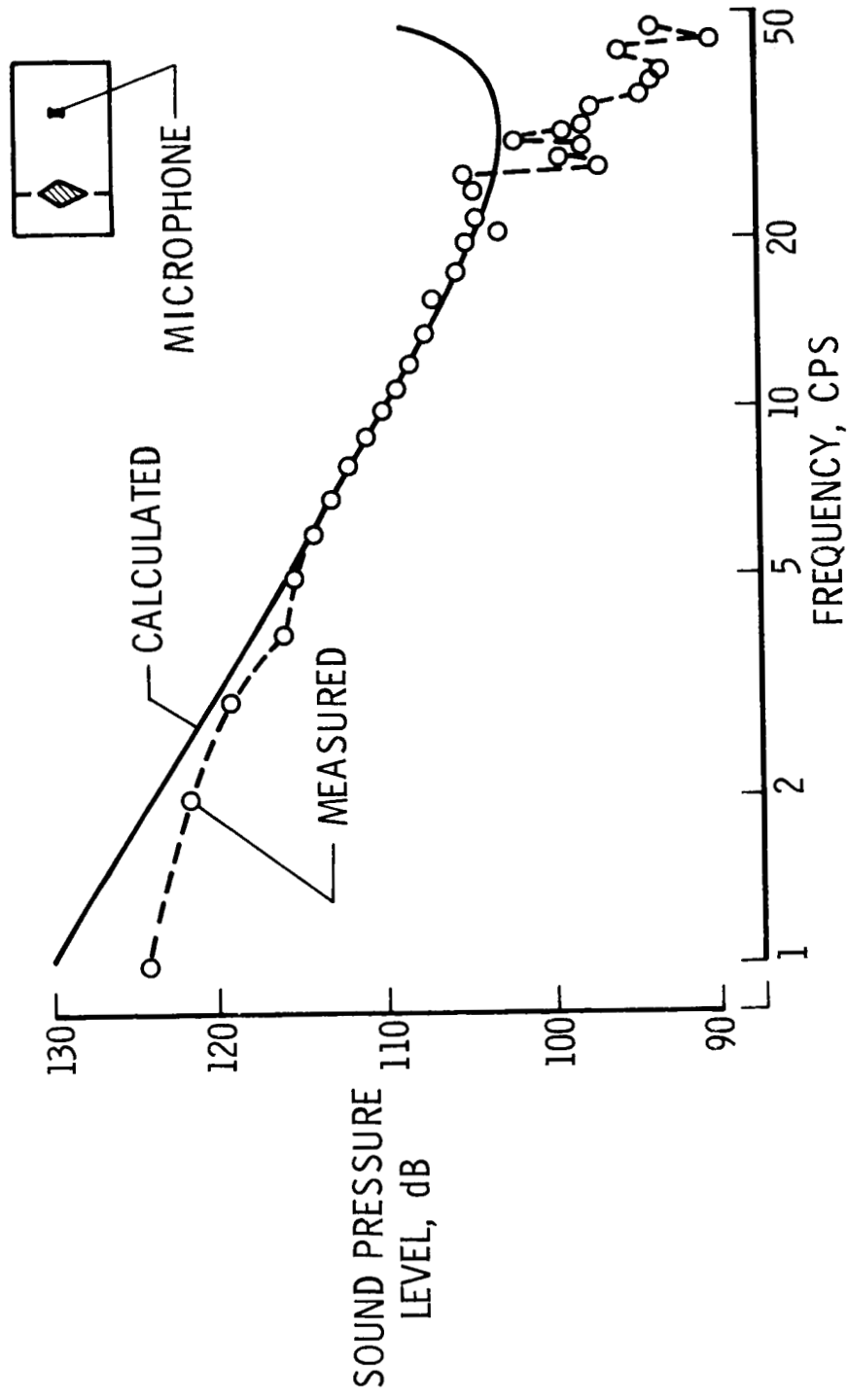


Figure 4.- Schematic diagram of the electrohydraulic driver system for the Langley Low-Frequency Noise Facility.



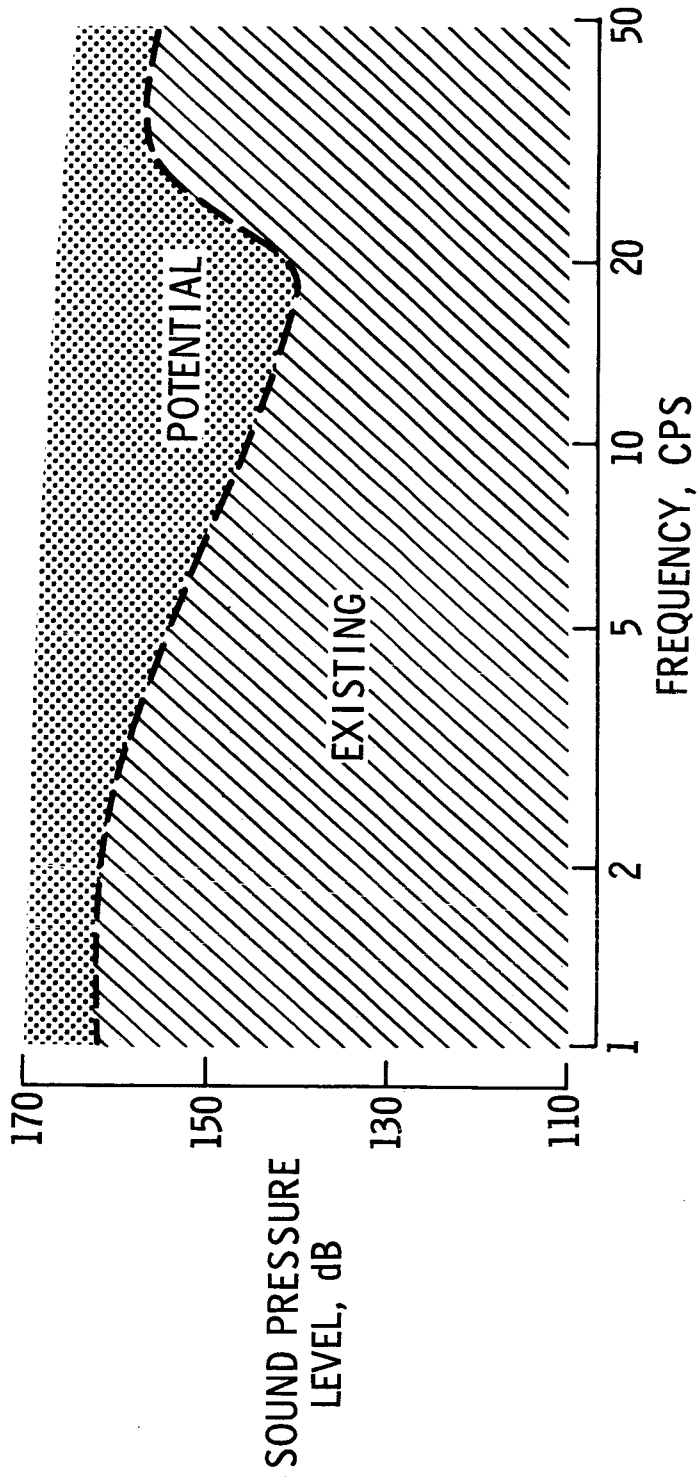
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Figure 5.- Design operating range of the hydraulic driver system for the Langley Low-Frequency Noise Facility.



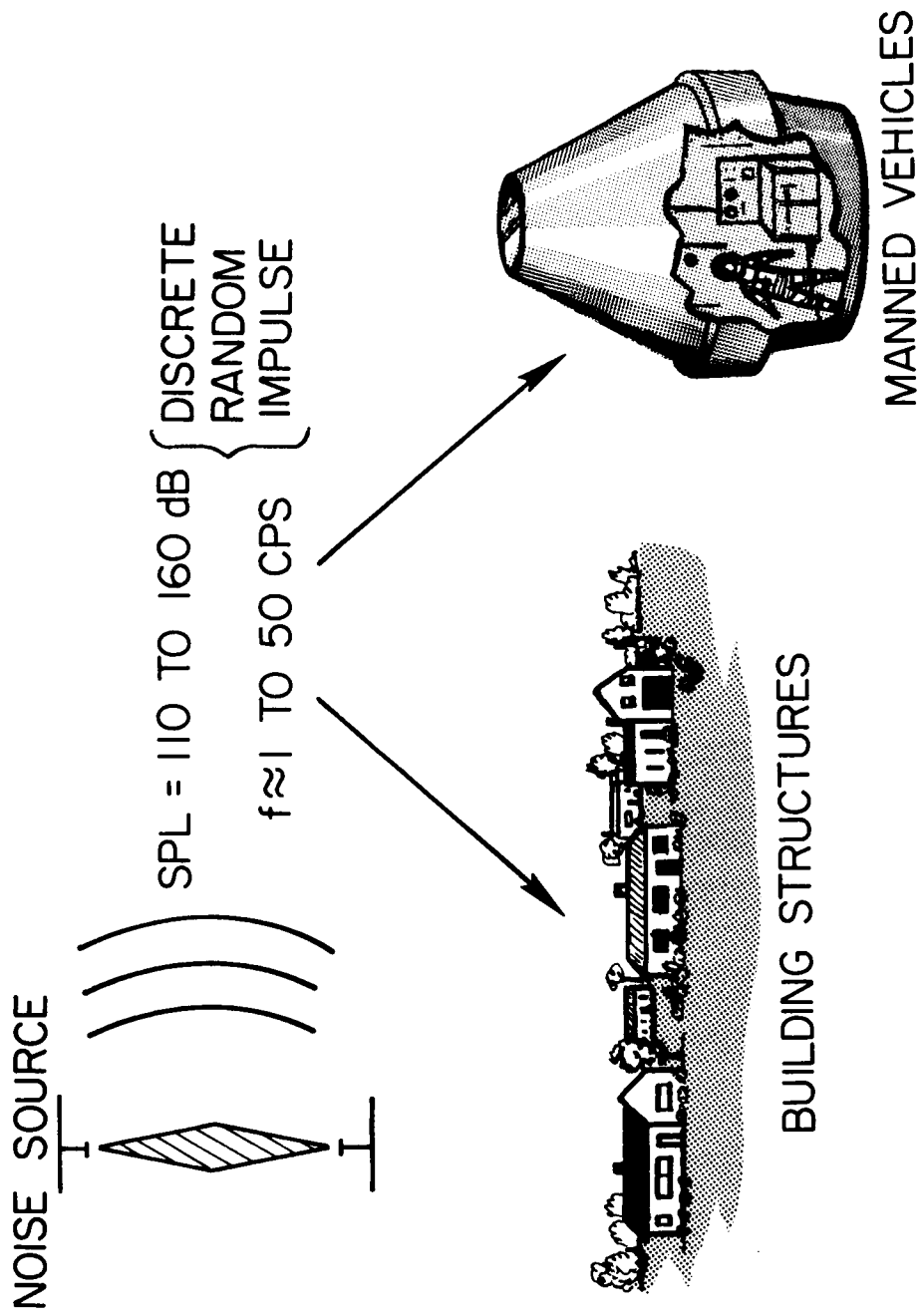
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Figure 6.- A comparison of measured and calculated sound-pressure levels in the Langley Low-Frequency Noise Facility for a driver piston velocity of 1 inch per second.



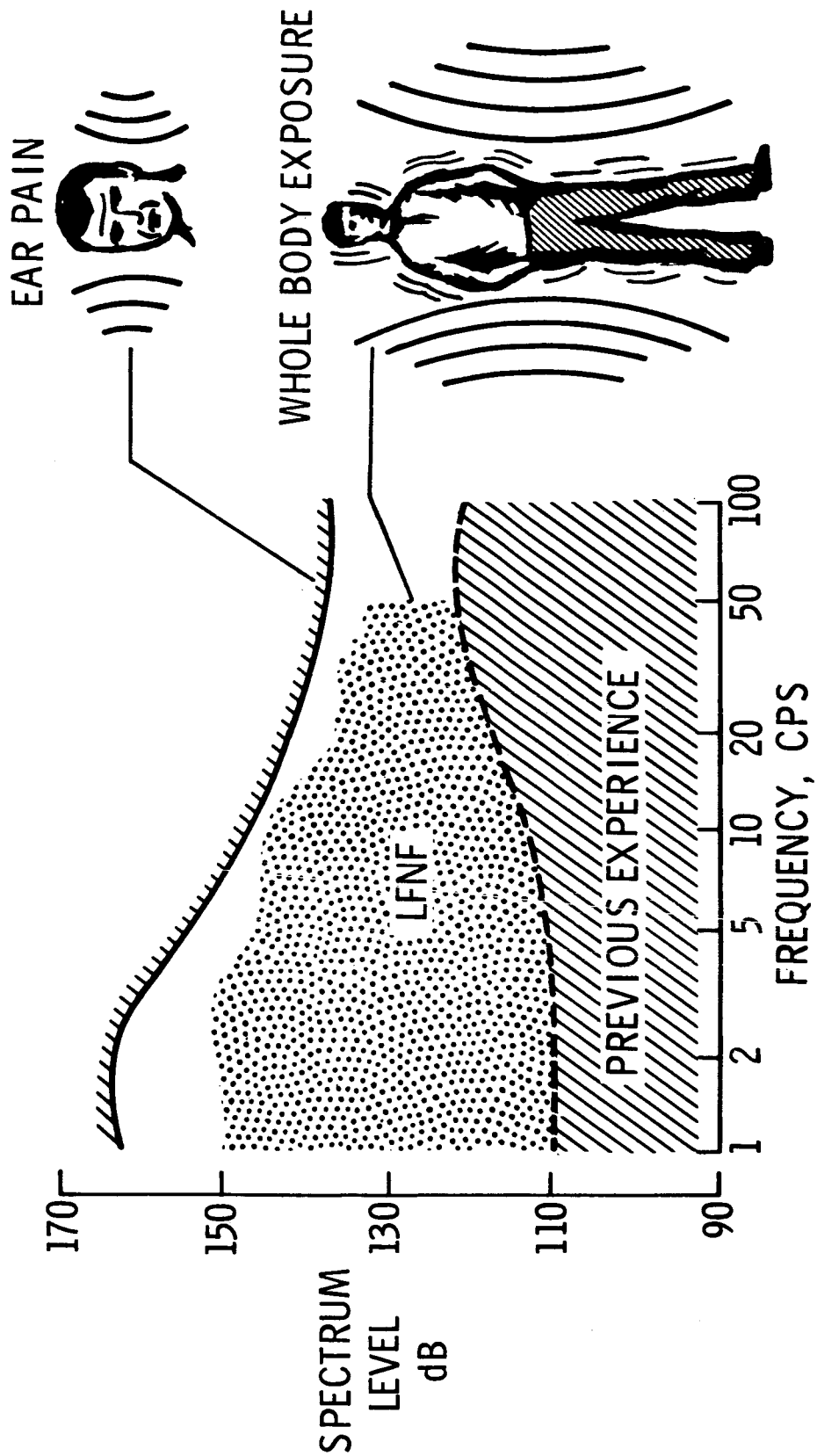
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Figure 7.- Existing and potential acoustic environment capability for the Langley Low-Frequency Noise Facility.



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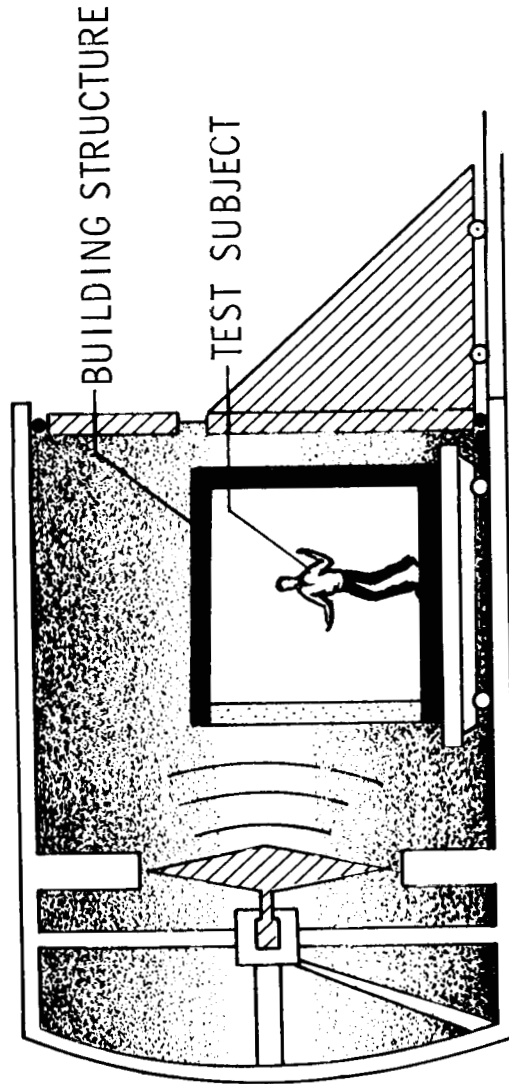
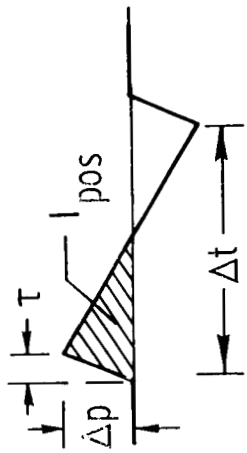
Figure 8.- Applications of the Langley Low-Frequency Noise Facility to the problem of environmental testing of flight vehicle and building structures.



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Figure 9.- Application of the Langley Low-Frequency Noise Facility to the problem of human whole-body exposure to noise.





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Figure 10.- Application of the Langley Low-Frequency Noise Facility to the problem of sonic-boom simulation.