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A DESCRIPTION AND SOME MEASURED ACOUSTIC CHARACTERISTICS OF THE LANGLEY 220 CUBIC METER REVERBERATION CHAMBER

by

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SUMMARY

An initial acoustic calibration has been performed for the NASA Langley Research Center reverberation chamber located in the Aircraft Noise Reduction Laboratory. Presented in this report are a description of the physical characteristics of the chamber and measured data for the ambient acoustic levels, reverberation times, reflection coefficients, the spatial uniformity of acoustic energy as measured in the 1/3-octave bands from 40 Hz to 10 KHz and acoustic power levels of a standard source. Measured power levels compared very well with those published for the ILG standard source. The measured data indicate that for broadband noise fields. the reverberation room has acceptable acoustic performance in the frequency range from 100 Hz to 8KHz.

INTRODUCTION

The NASA Langley Research Center, Aircraft Noise Reduction Laboratory, consists of several specialized facilities including an acoustic physics area, an interior effects room, an exterior effects room, an audiometric room, a reverberation chamber, an anechoic chamber and a flow duct. The relative sizes and locations of these areas are schematically represented in the plan view sketch of the laboratory in figure 1. The purpose of this paper is to describe the reverberation chamber of figure 1 and to report the results of the first phase of its acoustic calibration. Included are measured ambient noise elvels, reverberation times, reflection coefficients, broadband noise spatial uniformity data, and a comparison of power levels of a measured standard source with published values. A discussion of instrumentation, data acquisition, and analyses will also be presented.

The reverberation chamber is supplied with a source of quiet air for special tests involving aeroacoustic interactions and can be operated at reduced pressures down to 1/3 atmosphere to simulate aircraft and spacecraft interiors. No attempt is made to include any aerodynamic or aeroacoustic performance data. All data included herein relate to the nonairflow operational mode at full atmospheric pressure.

DESCRIPTION OF REVERBERATION CHAMBER

A plan view sketch of the reverberation chamber and adjacent laboratory areas is seen in figure 2. Its dimensions are approximately 6.1 m wide by 8.5 m long by 4.3 m high with reinforced concrete walls each having a nominal thickness of 46 cm. The volume is approximately 220 cubic meters and the total surface area of the room is approximately 229 square meters. The chamber weighs approximately 4.5×10^5 kg and rests on approximately 120 independent coiled springs, each with a stiffness of 1.4×10^5 kg/m and a fundamental resonance of about 3 Hz. Located in the center of the room is a pedestal completely isolated from the chamber floor; this pedestal provides a mount for experiments involving moving parts which need to be vibration isolated from the floor of the chamber. Surrounding this chamber is another room with 46 cm thick concrete walls. There is a minimum airspace of 30 cm between the external walls of the chamber and those of its enclosing room. The inside walls and ceiling are splayed, as suggested in the sketch of figure 2, in such a manner that there are no opposite parallel surfaces to sustain standing wave patterns, for the normal frequency range of operations.

Also shown in figure 2 are air ducts which penetrate the walls and permit airflow into and out of the chamber. Although this airflow capability is a special feature of the chamber, further consideration of its capacity and modes of operation are outside the scope of this paper. The existence of the air ducts is believed to have no appreciable effects on the acoustic performance of the chamber since massive flanges completely cover the duct openings for the measurements reported herein. The only anticipated impact on these measurements is a possible increase in the ambient noise level in the chamber due to transmission of noise from adjacent areas through the ducts. Another special feature of the chamber is that it was constructed with reinforced walls thus giving it the capability of withstanding a pressure differential of ± 10 psi. This makes it possible for the chamber to be evacuated to aircraft or spacecraft interior pressure conditions and also to be operated as a plenum chamber in the air system. The acoustic performance is not apt to be affected, except insofar as the added structural reinforcement of the chamber walls may determine their dynamic behavior

APPARATUS AND METHODS

The instrumentation setup used in the calibration is represented schematically in figure 3. This figure shows the block diagram of the signal input, acquisition, and analysis systems. All instrumentation was calibrated to factory specifications and met the criteria of reference 1. Excluding the sound sources, all pieces of instrumentation had a frequency response flat to within ±1 dB, over the frequency range of 10 Hz to 10 KHz. The microphones, which had flat pressure response curves, were the conventional condenser type using FET preamplifiers. Before and after each test operation, a single point (1 KHz signal at a level of 124 dB) acoustic calibration was performed on all microphones. All data were analyzed in real time.

Microphones were placed in the reverberation chamber at the locations indicated by the plan view sketch in figure 4. The microphones were all vertically oriented (diaphragm parallel to the floor), 1.67 meters above the floor and placed as shown in figure 4 relative to the sound sources. No microphone was nearer than 1.67 meters to any sidewall. These dimensions satisfy the acoustic requirement of having no boundary nearer to the microphone than a half wave length (ref. 1) for frequencies greater than 100 Hz.

One source used to generate acoustic signals in the chamber was an enclosed 12-inch diameter loudspeaker (source no. 1 of fig. 4). This speaker was located on the floor in a corner of the chamber. One-third octave band random noises at center frequencies of 40 Hz to 10 KHz and broadband random (40 Hz - 10 KHz) noises were separately played through the speaker to acoustically excite the room for acquisition of reverberation time and spatial uniformity data. The second sound source, located as shown in figure 4, is of the type shown in the photo of figure 5. It is a small centrifugal fan manufactured by ILG Industries, Inc. of Chicago, Illinois, and is commonly used for calibration purposes. It generates sound mechanically and is rated by the manufacturer for this particular application at an acoustic power level output of 87.5 dB relative to 10^{-12} watts. The locations for the speaker and ILG sound source conformed to the national standards (refs. 1 and 2).

The measurement of ambient noises in the reverberation chamber over a 24-hour period was accomplished in real time with microphone outputs both space averaged and individually sampled. The overall sound pressure levels were recorded on a graphic level recorder, and at arbitrary points in time, 1/3-octave band noise spectra from 10 Hz to 10 KHz were made.

To obtain the spatial uniformity of the acoustic signals in the chamber, a microphone scanner system was used. With reference to figure 4, the speaker was turned on, the sound field was allowed to stabilize, and the outputs of all four microphones were simultaneously scanned for the purpose of evaluating the uniformity of the overall sound pressure levels and spectra of the acoustic field in the chamber. The above scanner was capable of giving a sampled output from each microphone in a very short time, one microphone signal analyzed per 0.0008 sec, thus giving an almost instantaneous sampled output. Spectral analysis of the overall levels were accomplished at this scan rate in order to have a proper sampling time compatible with the lowest frequency of interest (ref. 3).

For reverberation time measurements, the acoustic field was allowed to stabilize, the speaker was cut off, and the microphone outputs were recorded as a function of time. The time for the acoustic signal to decay 60 dB was measured, thus giving reverberation times of the chamber from which reflection coefficients were calculated. For these measurements, the scanner was set at a scan rate of one microphone signal sampled every 0.0002 sec, and a high-speed graphic level recorder was used to record the decay of the acoustic signal (ref. 2). Each measurement was obtained 10 times at each 1/3-octave band center frequency of interest. The mean reverberation times and associated standard deviations were then calculated.

RESULTS AND DISCUSSION

Ambient noise data were measured on several occasions over a period of time and at various times of day. The overall noise level results for the frequency range 10 Hz to 10 KHz are shown schematically in figure 6 as a function of time of day. There is a baseline ambient noise which exists all during the day and is believed due to the normal utilities, equipment, and air handling machinery in the building. This noise has a flat broadband spectrum, with no identifiable discrete frequencies and its overall noise level varies between about 30 dB and 45 dB as indicated in the figure.

During the hours of normal work schedules in the adjacent shop area short duration noises are observed in the reverberation chamber that occasionally reach levels of about 55 dB. These levels are associated with noises resulting from routine machine shop operations and model preparation work. These short duration noises are not normally observed at times other than when shop work is in progress.

Spatial Uniformity of Acoustic Levels

One criterion for the performance of a reverberation chamber is the spatial uniformity of the spectrum of a broadband noise source measured simultaneously at different locations. Figure 7 shows this spatial uniformity by presenting the extreme values of the sound pressure levels measured in each 1/3-octave band at the four microphone locations of figure 4. It can be seen from the hatching that the measured differences are within ±1 dB at all frequencies above 100 Hz. This relatively small spread in levels suggest an acceptable state of diffuseness above 100 Hz (ref. 1). Below 100 Hz, it can be seen that the spread in levels is greater. This is to be expected, as the wavelengths below 100 Hz are beginning to approach the dimensions of the chamber (refs. 4 and 5).

Reverberation Times

In order to be able to calculate the reflection coefficients of the chamber and the acoustic power levels of a source in the chamber, it is necessary to know the reverberation times in each of the frequency bands of interest. With this in mind, mean reverberation time (time for signal to decay 60 dB, T_{60} secs) data were obtained using the precedures previously outlined, and are presented in table I. This table presents the computed mean and standard deviations for 10 reverberation time trials, at the 1/3-octave band center frequencies from 40 Hz to 10 KHz. The calculated mean reflection coefficients ($\overline{r}$) (percentage of incident energy that is reflected) are also presented.

Figure 8 is a plot of the 1/3 octave band mean reverberation times from table I. It may be seen that the reverberation times decrease from approximately 65 sec at 40 Hz, to less than 2 sec at 10,000 Hz. It is believed that the relatively high reverberation times for the frequencies below 100 Hz result at least in part from the high stiffness construction of the chamber walls which are designed for high differential pressures. The above effect occurs generally outside of the normal operating region and, hence, is of only academic interest. The trend of decreasing reverberation times with increasing frequency in the normal operating range is to be expected because more acoustic energy is absorbed within the chamber by the air and by the walls at the higher frequencies (ref. 6).

Mean Total Reflection Coefficients

Figure 9 presents the mean total reflection coefficients ($\overline{r}$) from table I as calculated from the data of figure 8. It can be seen that in the normal operating range, calculated reflection coefficient values vary from about 99 percent down to about 91 percent. The relatively high value at frequencies below 100 Hz are believed to result from the unusual wall construction noted above. At higher test frequencies, the lower reflection coefficients are believed to result from increased air and wall surface absorption (see ref. 6).

Power Levels of Standard Source

An overall performance evaluation of the reverberation chamber was made by measuring the 1/3 octave band power levels of a standard sound source and by comparing these data with the published levels of the source (refs 1 and 5). The measured noise levels (SPL), in each 1/3 octave band were converted to acoustic power levels (PWL), by the use of the following equation from references 1 and 7:

$$PWL = SPL + 10 \log \left[\frac{V}{T_{60}} \left(1 + \frac{S\lambda}{8V}\right) \right] - 14 \quad \text{re } 10^{-12} \text{watts} \quad (1)$$

where V is chamber volume, S is chamber area, and λ is the wave length of the respective 1/3 octave band center frequency. The second term on the right-hand side of the equation, defined as k(f), can be evaluated at each 1/3 octave band center frequency of interest for given values of volume and surface area of a particular chamber. For convenience this has been done for the ANRL reverberation chamber and the results are presented in figure 10. Shown in figure 10 is a plot of K(f) values over a range of frequencies for use in converting measured Sound Pressure Level values directly to Power Level values. As an example of the use of figure 10, for a measured environmental SPL value of 130 dB in the 3150 Hz band, the associated source PWL would be 130 plus 2 = 132 dB.

Each of the 1/3 octave bands containing the center frequency of interest in the filters of a real-time analyzer can be adjusted by these K(f) values of figure 10, as appropriate, to display directly the sound power levels (ref. 7).

Figure 11 presents a comparison of the 1/3 octave band power determined by the above procedure with similar data furnished by ILG

Industries, Inc., for the standard sound source. For convenience, the ILG data are also listed in table II. For each center frequency the mean values and standard deviations are shown. A study of figure 11 indicates good agreement between the measured values and those furnished by ILG Industries, Inc. In the normal operating range of the chamber the 1/3-octave band power levels agree generally within ±1 dB and the total power levels agree within 0.4 dB.

OVERALL ACOUSTIC PERFORMANCE

Based on the measurements already presented, it is possible to predict the sound pressure level environment in the chamber for a known broadband acoustic source, as shown in figure 12. For instance, for the 1/3-octave band having a center frequency of 8,000 Hz, the sound pressure level environment in the chamber will vary from 114 to 134 dB for a source power variation of 1 to 100 acoustic watts. For a center frequency of 100 Hz a given noise level can be achieved with about an order of magnitude less acoustic power.

Data for other frequencies in the operating range fall between the two curves of figure 12. The data of figure 12 can also be used to determine the required acoustic source power to produce a given environmental sound pressure level.

CONCLUDING REMARKS

Initial calibration results of the Langley 220 cubic meter reverberation chamber have indicated that it has generally acceptable overall acoustic performance for broadband noise in the normal operating range of about 100 Hz to 8,000 Hz. Its baseline ambient noise levels do not exceed 45 dB except for occasional short duration peak noises of up to 55 dB due to shop work. For broadband noise spectra the 1/3-octave band levels were noted to be within ± 1 dB as measured at four different locations in the room during spatial uniformity tests. Reverberation times follow the expected trends except at very low frequencies where large durations are believed due to added stiffness of the reinforced walls. Measured acoustic power from a standard ILG broadband noise source resulted in values with 0.4 dB of the furnished data for that source.

REFERENCES

1. American National Standard for the Determination of Sound Power Levels of Small Sources in Reverberant Rooms-ANSI Document-S 1.21-1972.

2. Standard Method of Test for Sound Absorption of Acoustical Materials in Reverberation Rooms-ANSI Document-S 1.7-1970.

3. Instrumentation for Space Averaging Sound Pressure Levels by E. John Wooten, J. Sound & Vibration (1971) 16(1), 59-69.

4. Diffusion in Reverberation Rooms - T. J. Schultz - J. Sound and Vibration, 1971, 16(1), 17-28.

5. Noise and Vibration Control-Beranek-1971 Edition.

6. The Upper Limits for the Reverberation Time of Reverberation Chambers for Acoustic and Electromagnetic Waves, K. Walther, JASA, vol. 33(3), Feb. 1961.

7. Acoustic Measurement of Sound Power Levels without a Computer, by W. R. Raymond, presented at the Noise and Vibration Conference, 1974, Monash University, Melbourne, Australia.

TABLE I. - Measured Mean Reverberation Times And Standard Deviations; and Calculated Mean Total Reflection Coefficients, as a Function of Frequency.

1/3 OCTAVE BAND CENTER FREQUENCY Hz	MEAN REVERBERATION TIME (T_{60}) sec	MEAN TOTAL REFLECTION COEFFICIENTS ($\bar{r}$) percent
40	65.2±12.4	99.75
50	50.3±2.1	99.68
63	48.1±3.7	99.67
80	41.9±3.6	99.62
100	26.5±2.8	99.40
125	15.6±1.8	98.98
160	17.4±0.5	99.08
200	21.6±0.9	99.26
250	19.0±0.8	99.16
315	18.1±1.6	99.12
400	17.3±1.2	99.08
500	16.4±1.0	99.02
630	13.7±0.1	98.80
800	11.9±0.4	98.70
1000	11.4±0.5	98.60
1250	9.9±0.6	98.40
1600	8.0±0.3	98.00
2000	6.8±0.6	97.70
2500	6.7±0.4	97.60
3150	5.8±0.2	97.20
4000	4.6±0.3	96.50
5000	3.7±0.1	95.70
6300	2.6±0.05	93.90
8000	2.3±0.1	93.00
10,000	1.8±0.07	91.10

TABLE 2. - ILG Standard Sound Source Power Levels Determined By Reverberation Room Method As Furnished by ILG Industries Inc., Chicago, Ill.

1/3 OCTAVE BAND CENTER FREQUENCY HZ	SOUND POWER, dB re 10^{-12} watts	STANDARD DEVIATION $\pm$ dB
40	70.5	3.0
50	72.5	3.0
63	73.5	2.5
80	72.0	1.0
100	70.5	0.5
125	72.0	0.5
160	73.5	0.5
200	73.5	0.5
250	74.0	0.5
315	74.5	0.5
400	74.5	0.5
500	74.5	0.5
630	74.0	0.5
800	74.0	0.5
1000	74.5	0.5
1250	75.5	0.5
1600	75.0	0.5
2000	74.5	0.5
2500	74.0	0.5
3150	73.5	0.5
4000	73.0	0.5
5000	73.0	0.5
6300	73.0	1.0
8000	75.5	1.5

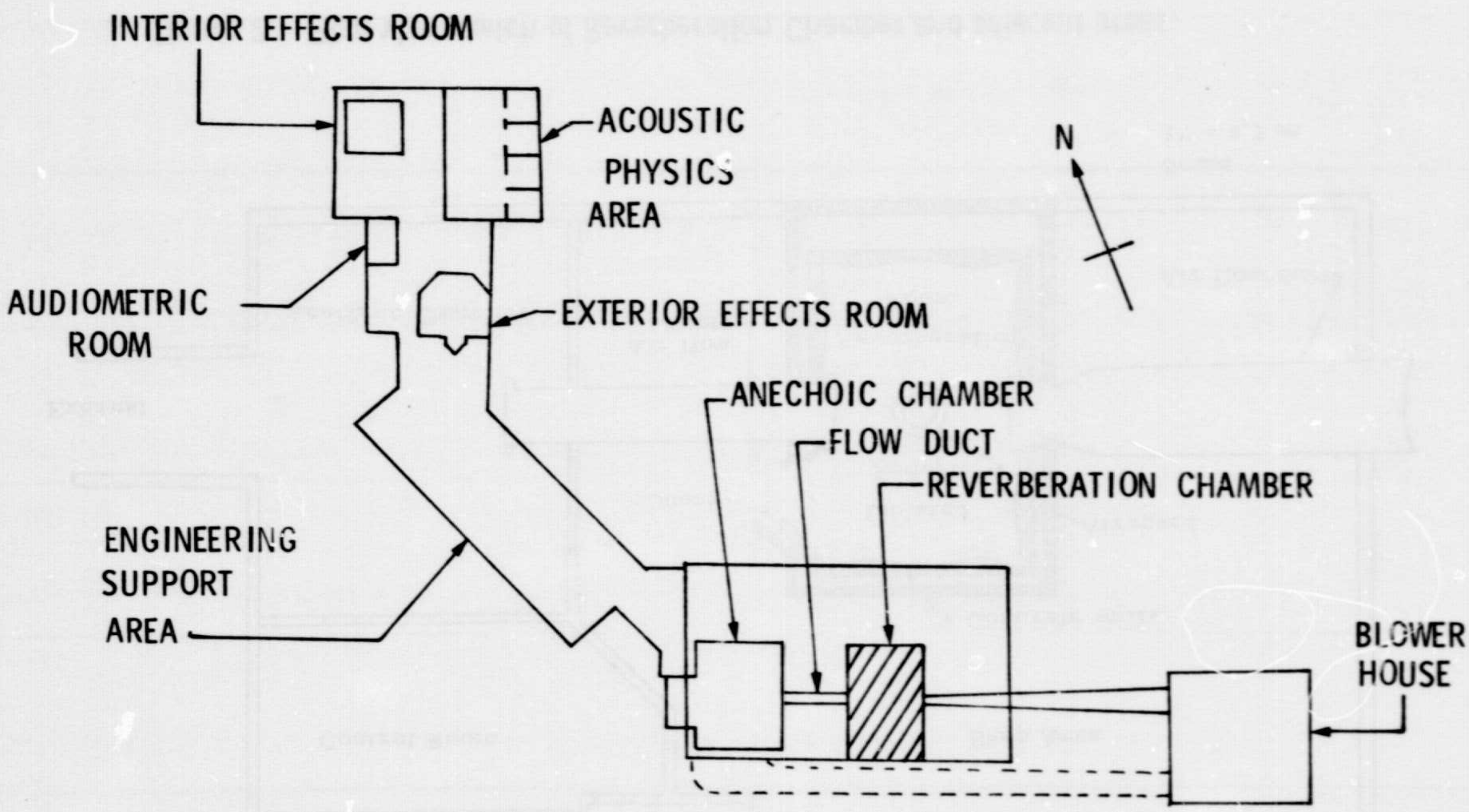

Figure 1. - Plan view sketch of aircraft noise reduction laboratory.

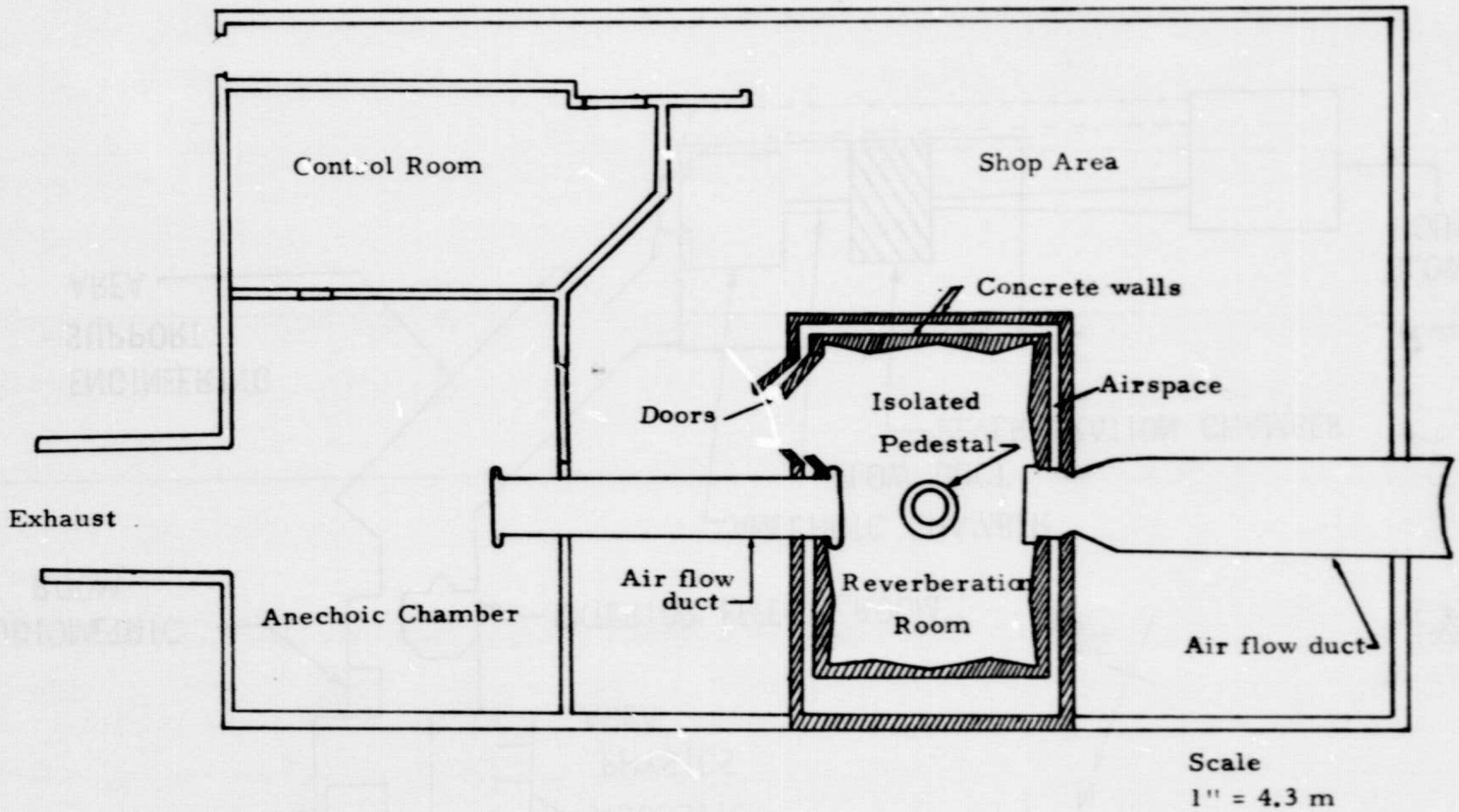

Figure 2. - Plan view sketch of Reverberation Chamber and adjacent areas.

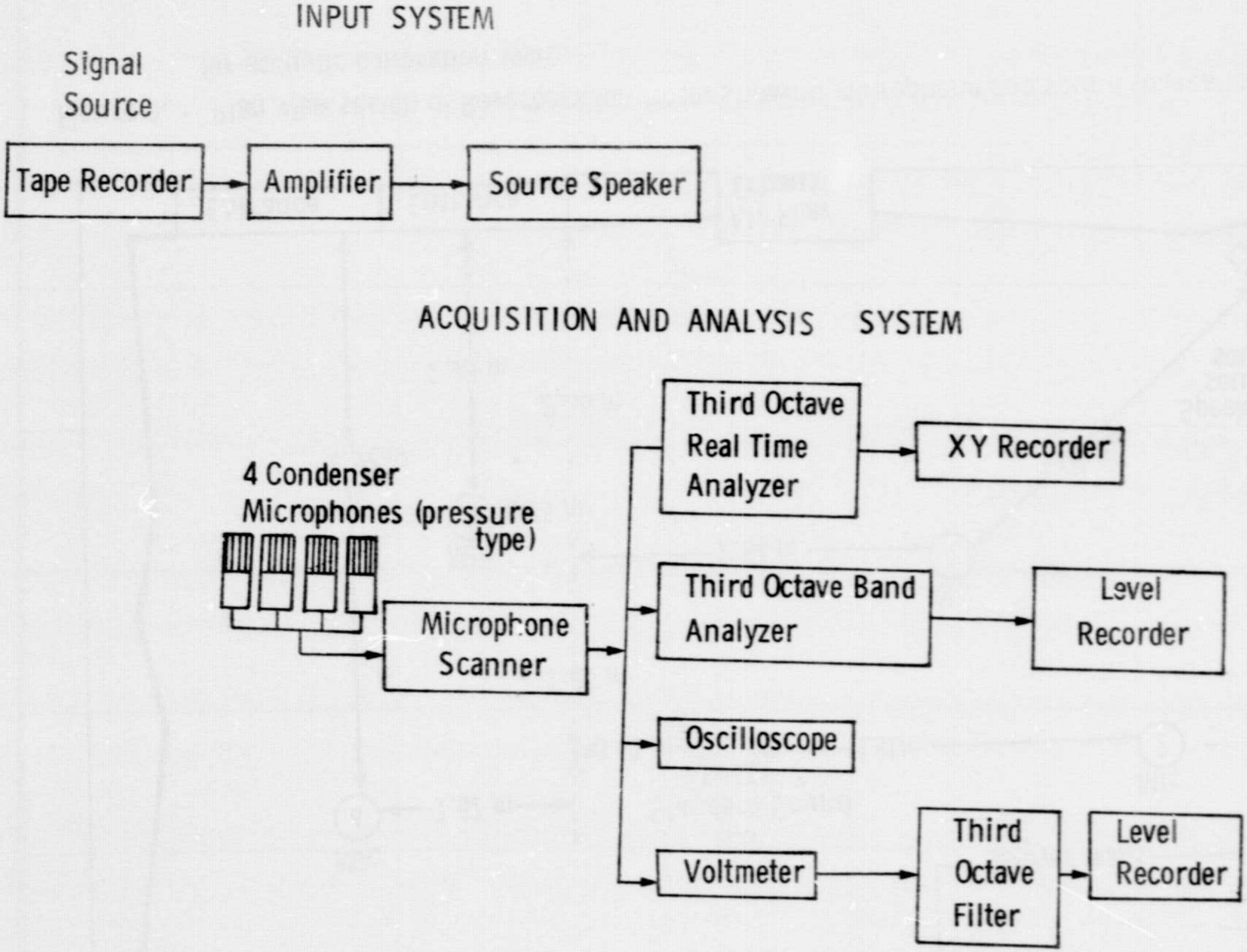

Figure 3. - Block diagram of instrumentation used in acoustic calibration of Reverberation chamber.

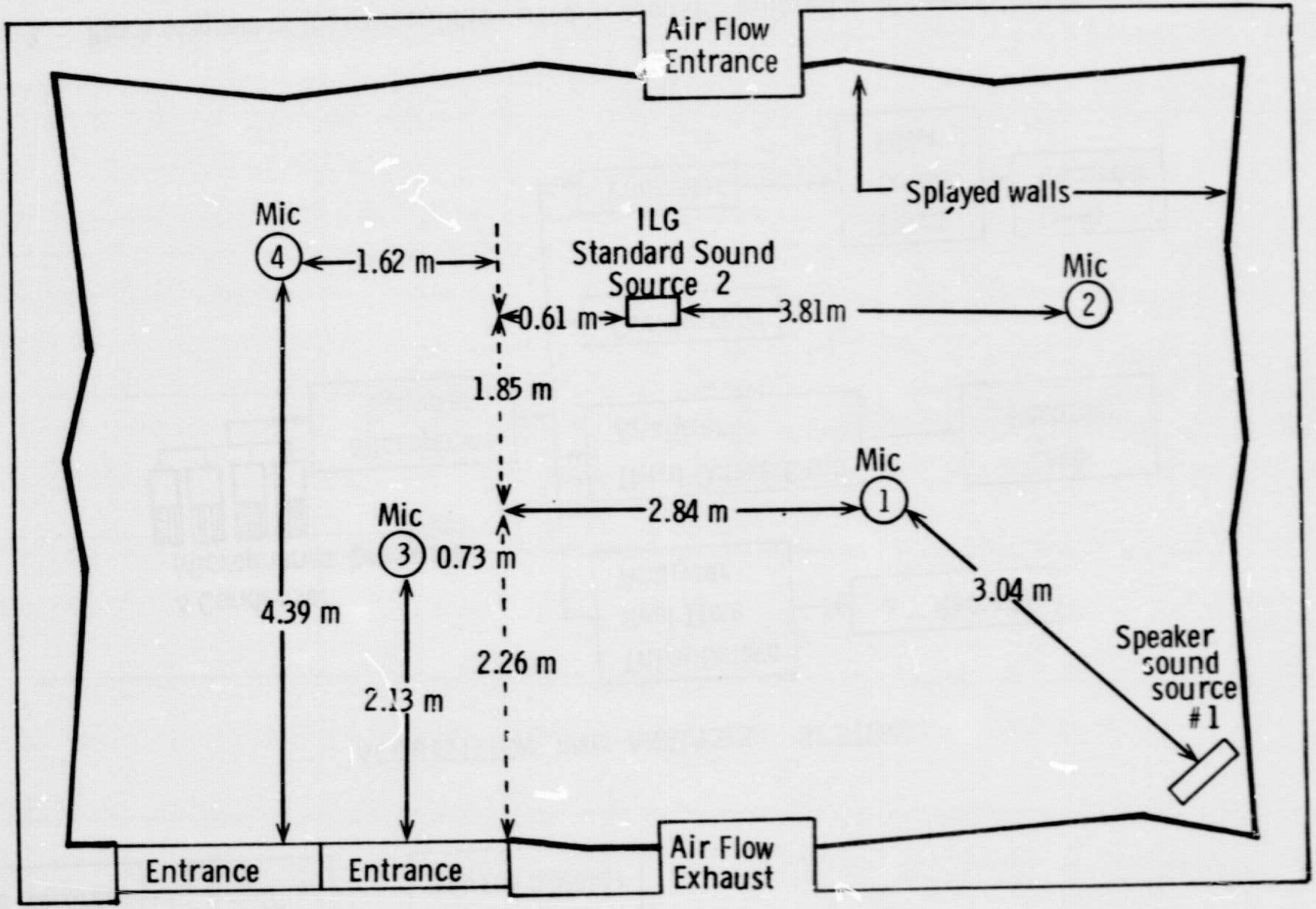

Figure 4. - Plan view sketch of Reverberation Room showing microphone and sound source locations for acoustic calibration tests.

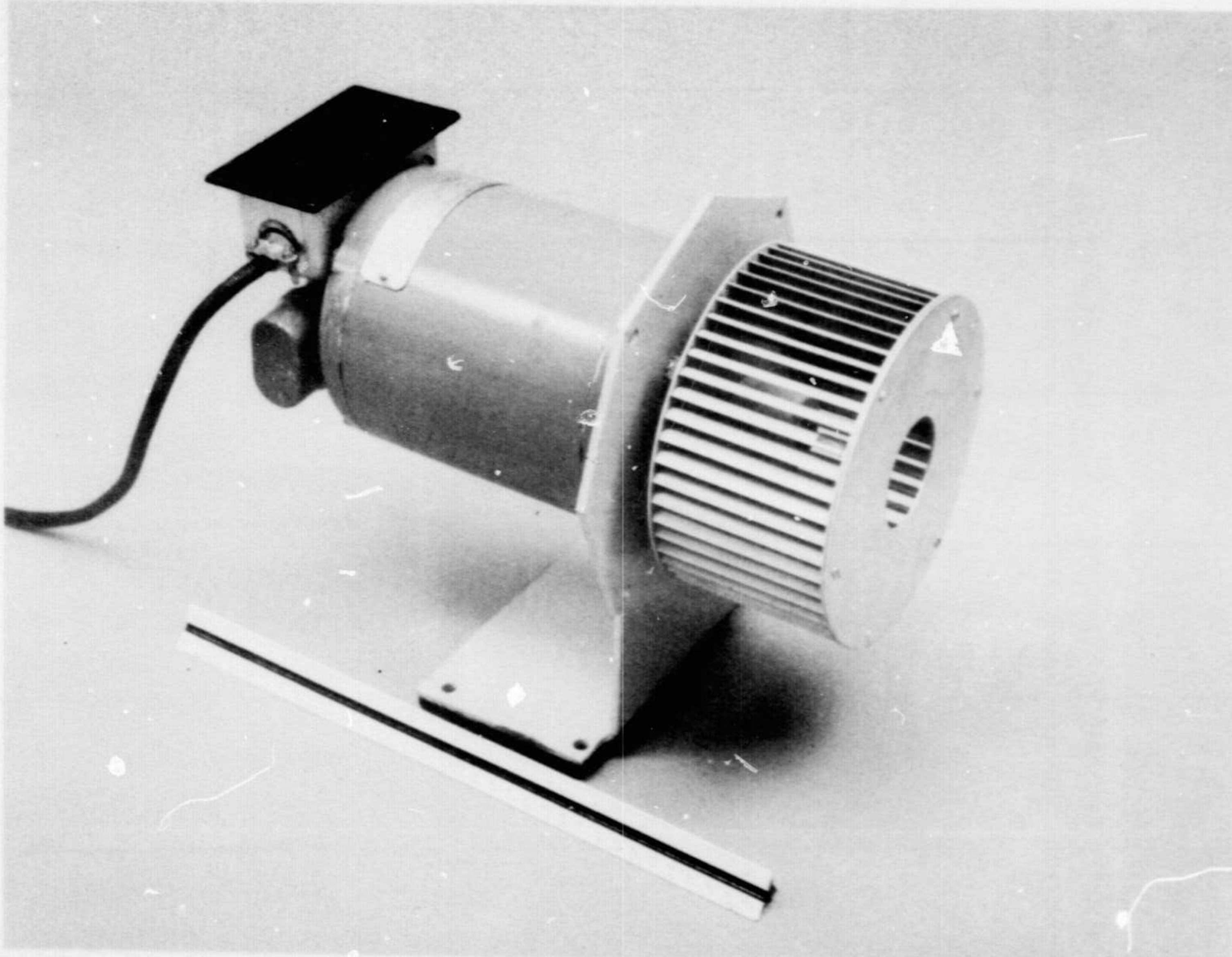

Figure 5. - Photograph of ILG standard sound source.

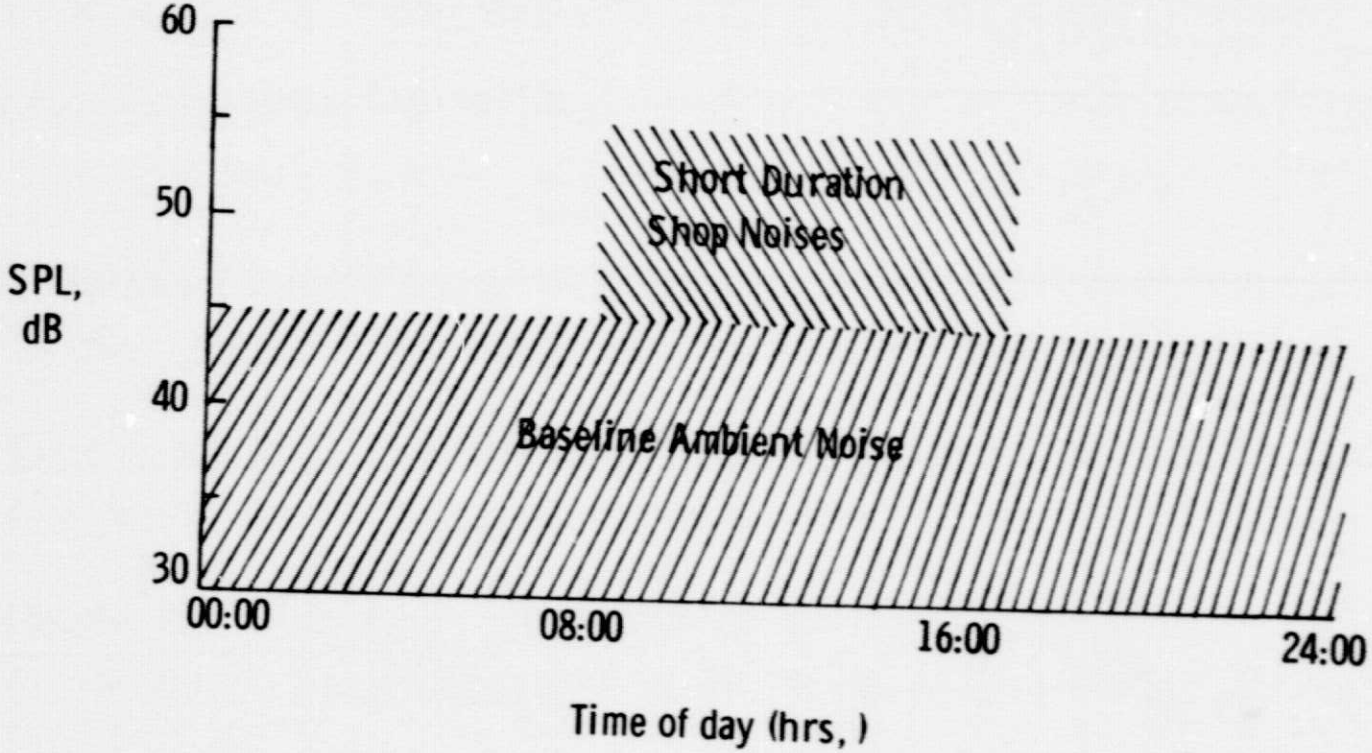

Figure 6. - Measured overall ambient noise levels in the ANRL Reverberation chamber over a 24 hour period.

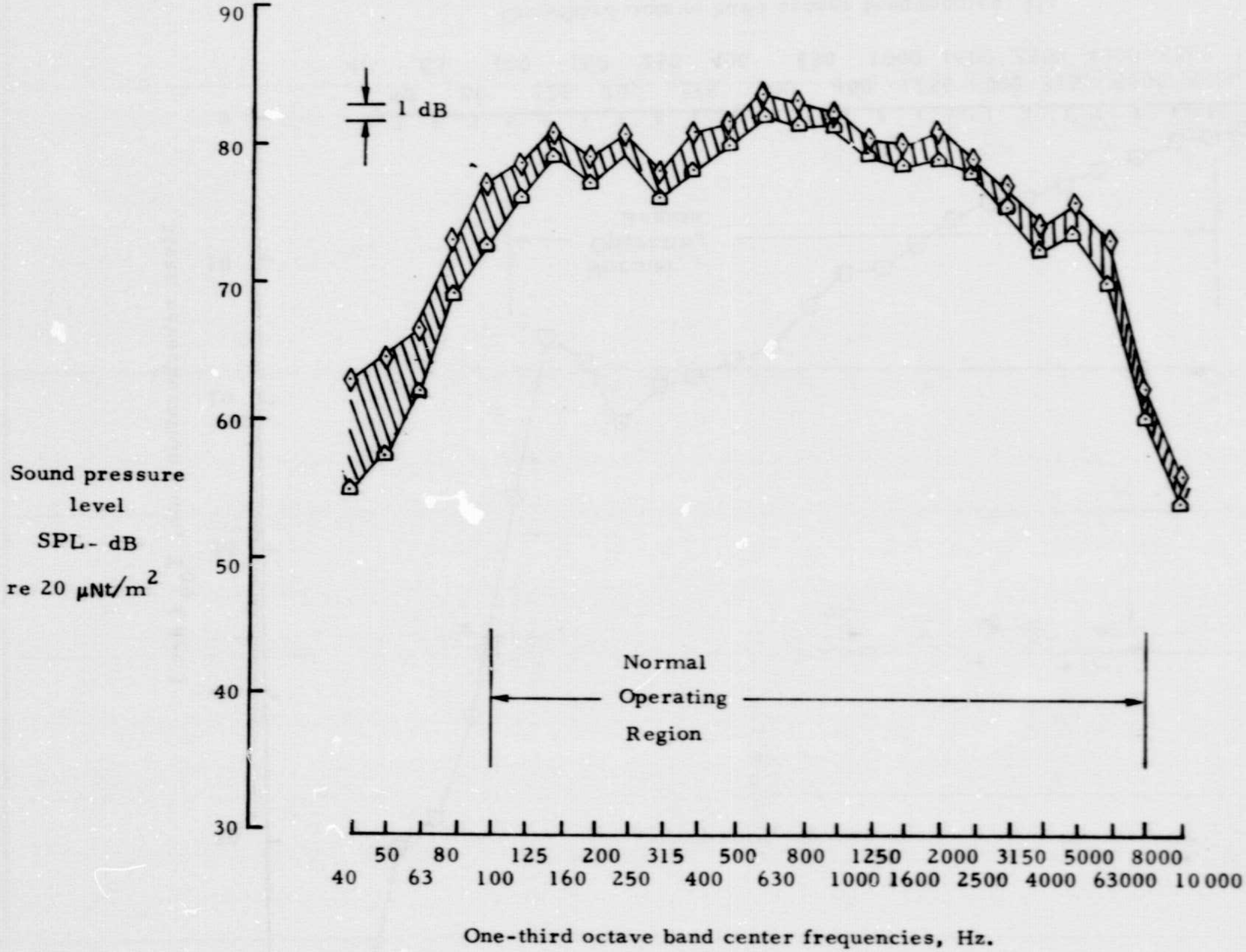

Figure 7. - Spread of measured broad band noise spectra at four microphone locations in the Reverberation Chamber.

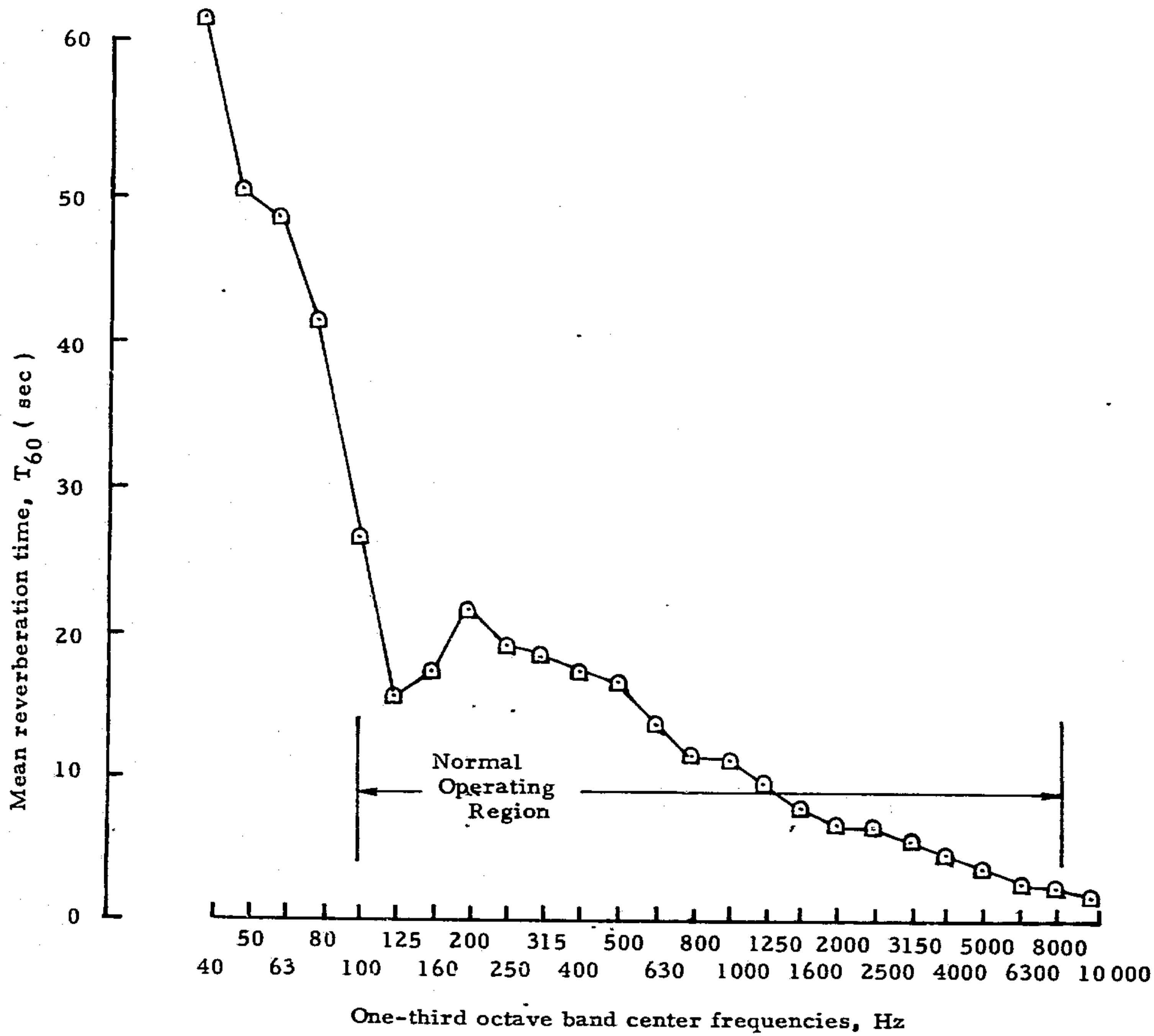

Figure 8. - Measured mean reverberation times as a function of frequency.

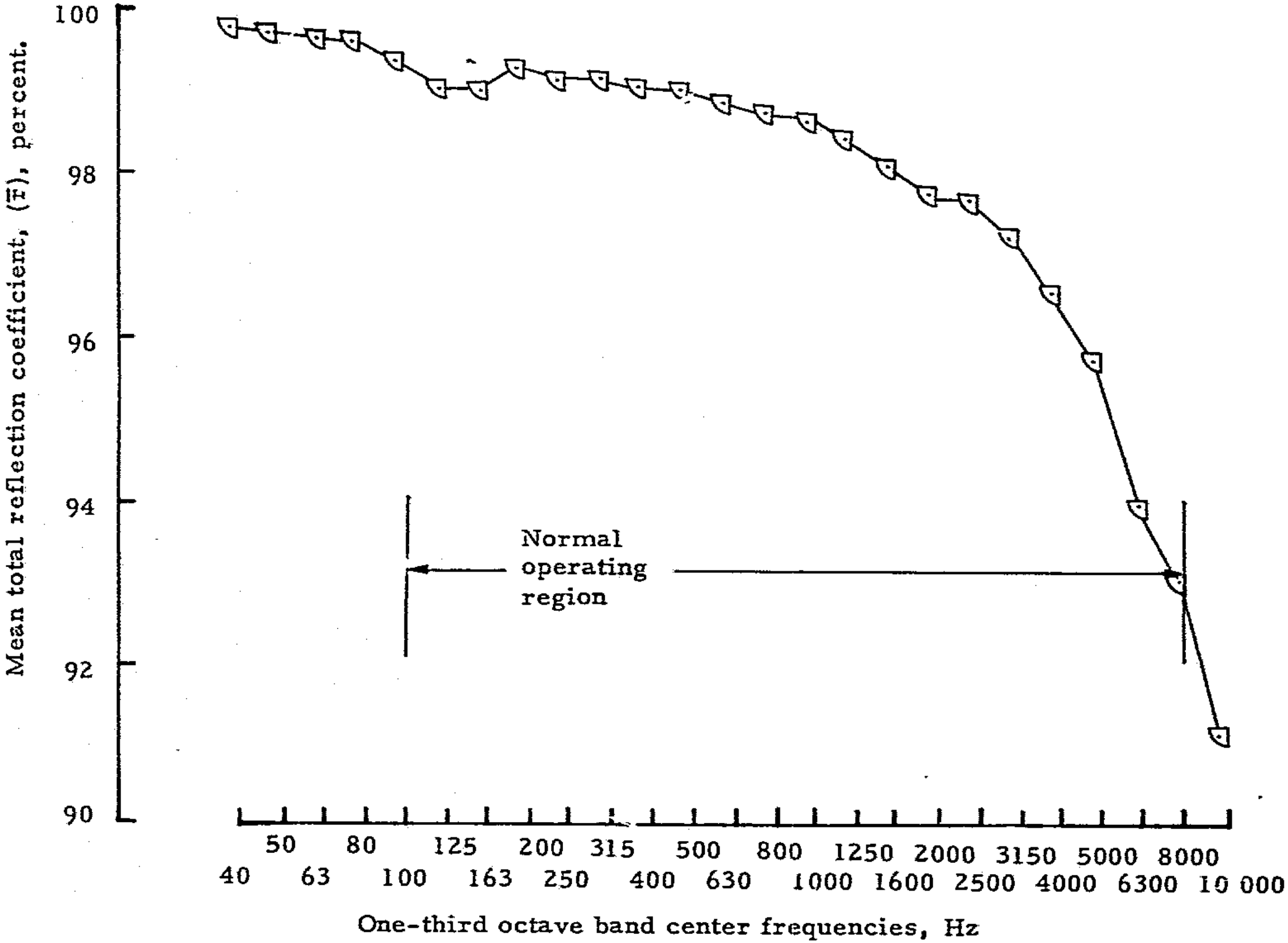

Figure 9.. Calculated mean total reflection coefficients, based on measured reverberation times.

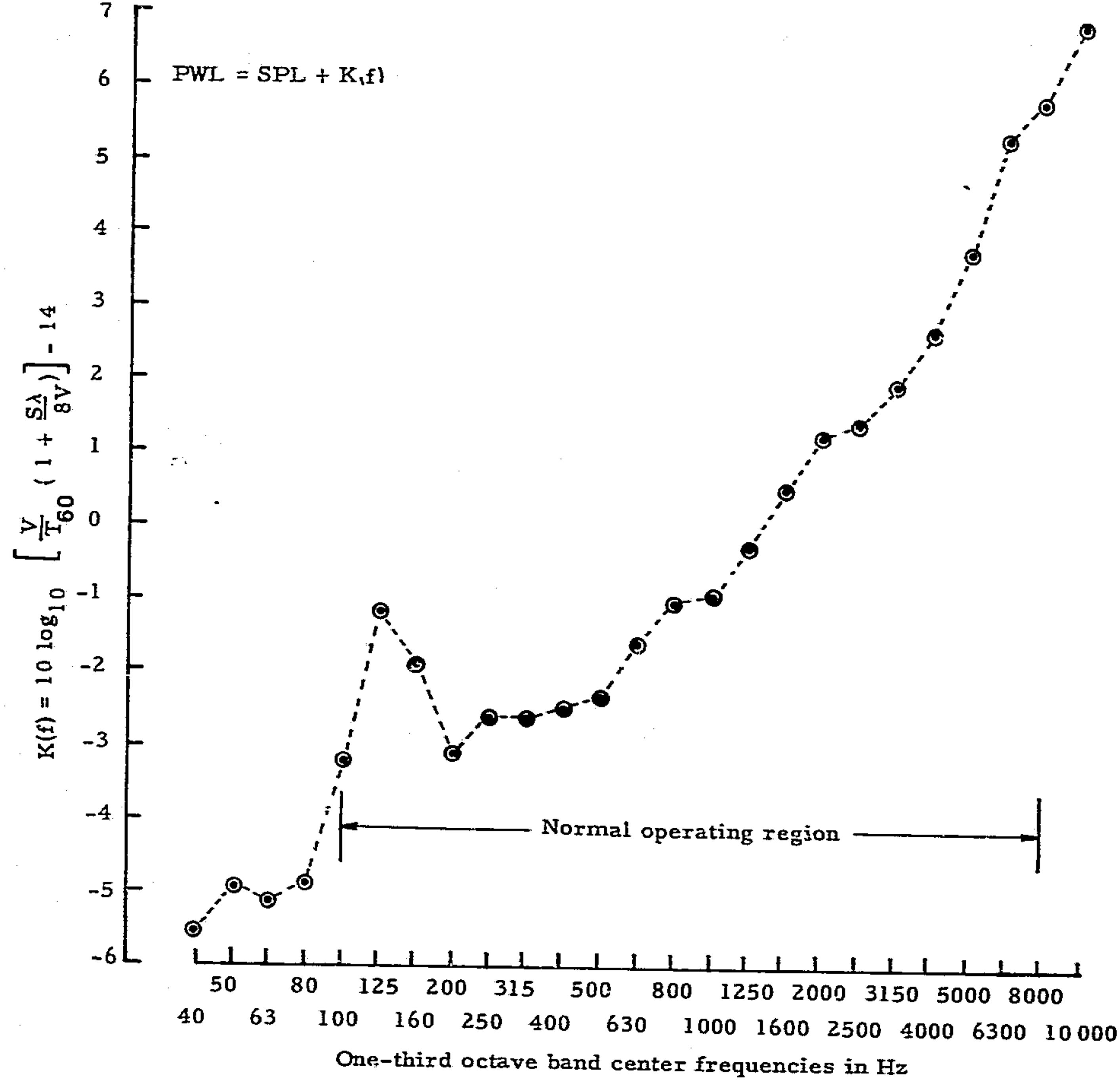

Figure 10. - Conversion curve of sound pressure level to sound power level for the ANRL Reverberation Chamber.

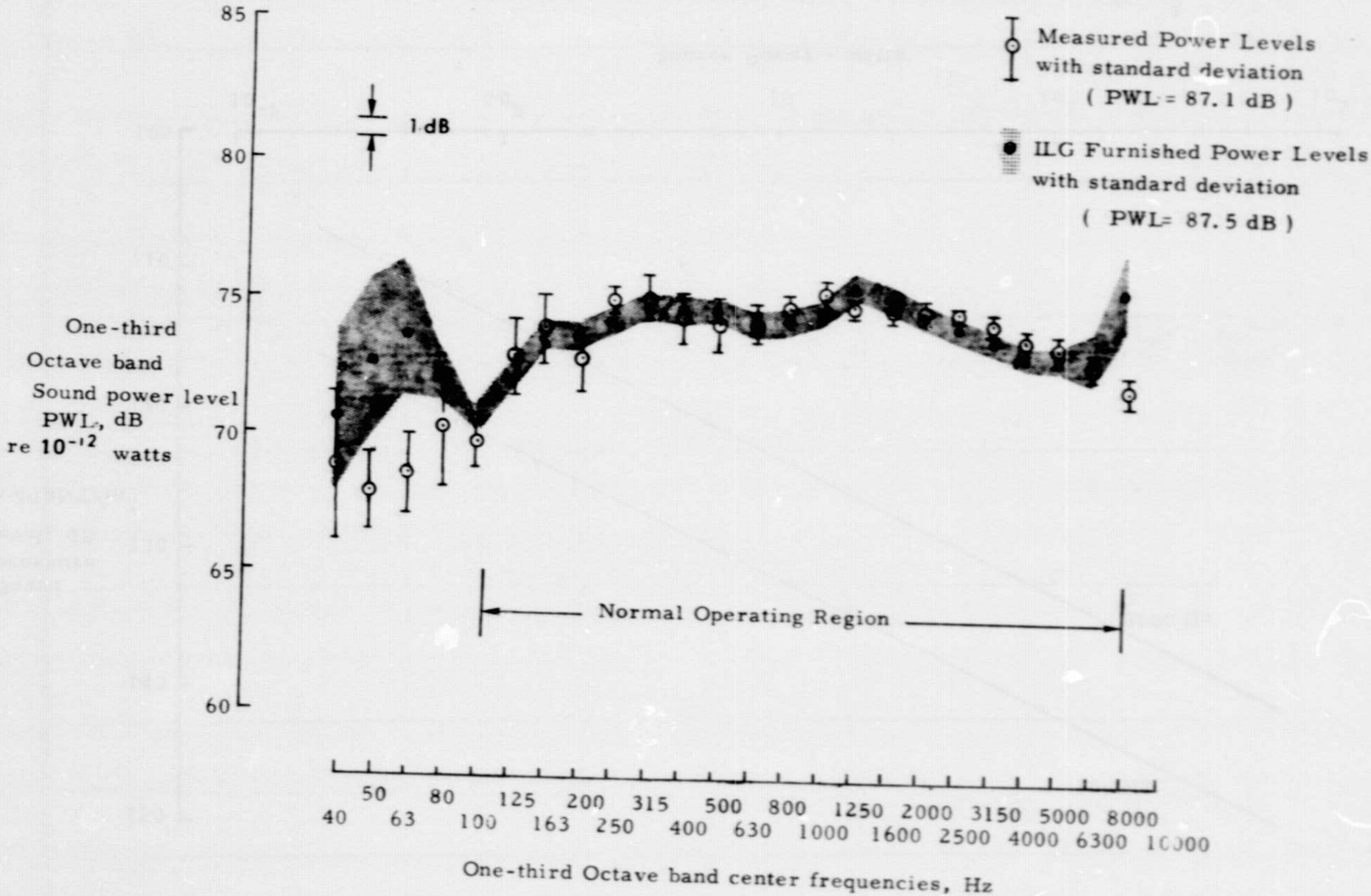

Figure 11. - Comparison of measured and furnished power levels for "standard" source.

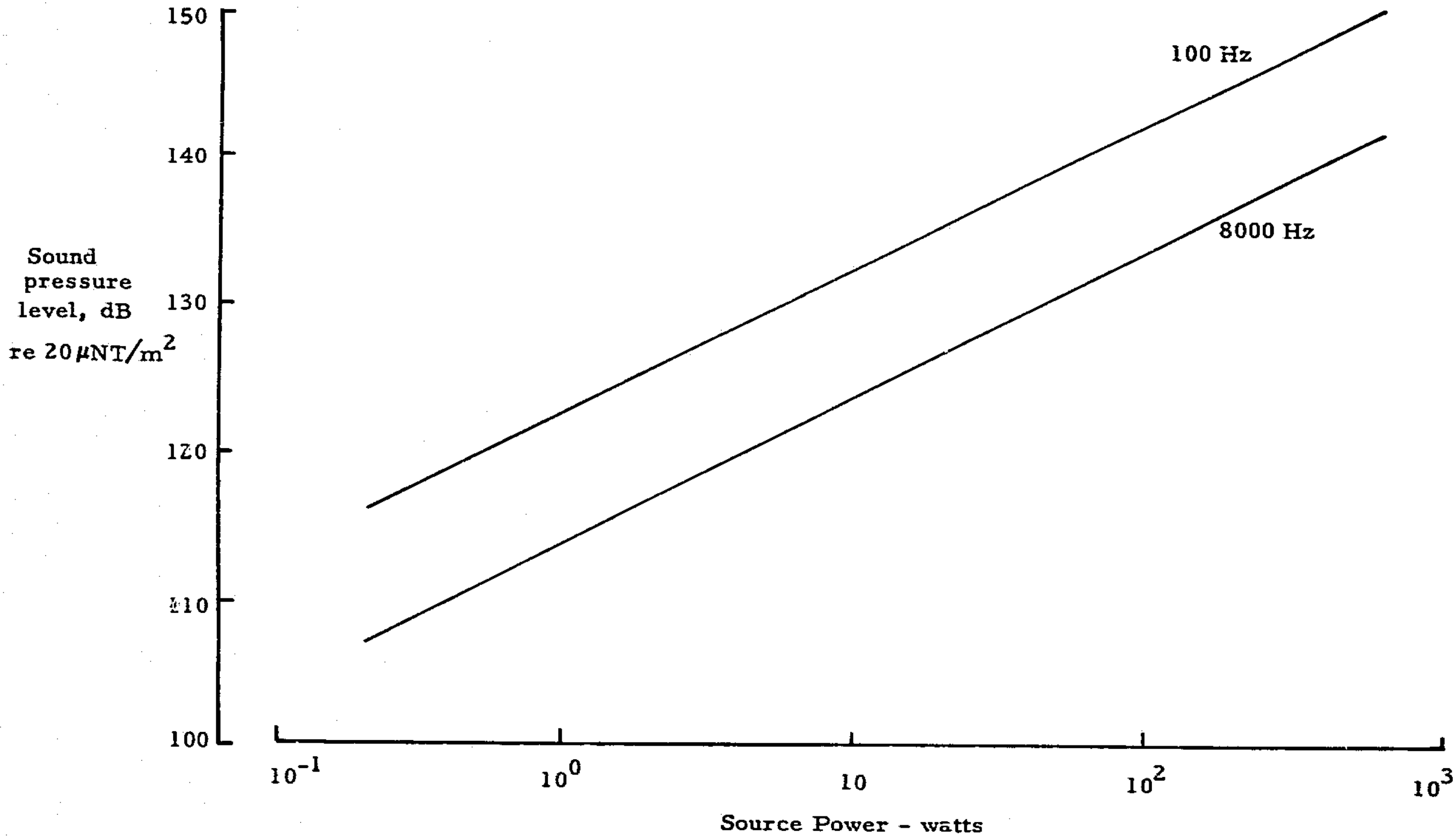

Figure 12. - Predicted broad band environmental noise levels in the Langley 220 m^3 Reverberation Chamber as a function of source acoustic power.