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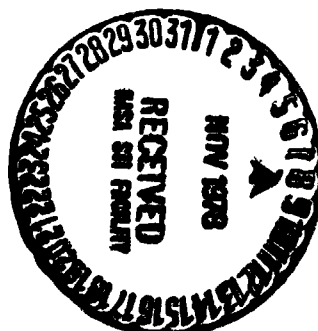
**NOISE-INDUCED BUILDING VIBRATIONS CAUSED BY CONCORDE
AND CONVENTIONAL AIRCRAFT OPERATIONS AT DULLES AND
KENNEDY INTERNATIONAL AIRPORTS
FINAL REPORT**

STAFF-LANGLEY RESEARCH CENTER

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**NOISE-INDUCED BUILDING VIBRATIONS CAUSED BY CONCORDE AND CONVENTIONAL
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FINAL REPORT**

By Staff-Langley Research Center*

SUMMARY

Measurements were made of aircraft noise-induced building vibrations near Dulles International Airport and John F. Kennedy International Airport as part of the Concorde monitoring program. Results of these measurements indicate that vibration levels are directly proportional to unweighted sound pressure level and are independent of other noise source differences. In particular, no evidence was found to suggest that Concorde is more efficient at inducing structural vibration than conventional aircraft. Vibration levels which occurred during Concorde operations were higher than those occurring during conventional jet operations due to correspondingly higher noise levels. In general, vibration levels due to aircraft noise were lower than vibration levels due to common domestic events and well below established structural damage criteria. Results of subjective measurements conducted as part of this program indicate that noise levels in excess of about 100 dB (unweighted) are required to induce floor vibration levels above the human detection threshold.

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INTRODUCTION

The structural response of historic and residential buildings to aircraft noise and the associated potential for structural damage and human annoyance have been the subject of public concern in the United States since the decision was made to introduce the Concorde supersonic transport here in 1976 (ref. 1). In response to this concern, the NASA, in cooperation with the FAA, made a series of aircraft noise and building response measurements in the neighborhoods surrounding Dulles International Airport and John F. Kennedy International Airport between May 1976 and March 1978.

NASA personnel and equipment were deployed to airport communities in Fairfax County, Virginia; Montgomery County, Maryland; and New York City a total of five times beginning in May 1976, when on a trial basis commercial Concorde service in the United States began at Dulles International Airport. The objective of the initial study was to assess the potential for noise-induced structural damage at Sully Plantation, an historic site located near the end of the runway most frequently used by Concorde (ref. 2). The data base established in this study was considerably expanded by data acquired in a second study conducted at Sully Plantation in June 1976 (ref. 3). A third study at Dulles involved residential structures in nearby Montgomery County, Maryland, the occupants of which had complained of Concorde noise-induced building vibrations (ref. 4). Results of all measurements in the Dulles vicinity are summarized in reference 5.

NASA personnel and equipment were deployed for the fourth and fifth times in support of the Concorde environmental impact assessment when Concorde operations began in New York at John F. Kennedy International Airport. Two

studies were conducted in the JFK area in January and February 1978, in which the physical measurement techniques which had been developed at Dulles to assess building damage potential were augmented by subjective measurements to study the mechanisms and threshold for human detection of aircraft noise-induced building vibration. Detailed results of these studies are reported in references 6 through 8.

The present report summarizes the results of the NASA effort for both the Dulles and JFK studies in support of the Concorde environmental impact assessment. Relationships observed between aircraft noise and building response are presented, as are peak measured levels of aircraft noise, noise-induced vibration, and vibrations due to common domestic events. The methodology is described for a simple pilot study to determine the threshold of human detection for vibration and rattle. Results of this pilot study are also presented.

METHOD

The approach to the physical assessment of Concorde noise-induced building vibrations involved three steps:

1. Measurement of indoor and outdoor noise and the corresponding acceleration levels induced in such structural elements as windows, walls, and floors.
2. Development of functional relationships ("signatures") between the vibration response of structural elements and the noise levels associated with events of interest.
3. Comparison of the Concorde-induced response with the response associated with other aircraft as well as with common domestic events or criteria.

The concept of a vibration/noise "signature" was conceived to investigate the relative effectiveness of various aircraft in exciting structural response. Each signature consists of a plot of acceleration levels for different sound pressure levels as in figure 1; a window response signature for a representative Concorde takeoff at Sully. The vibration levels resulting from other noise levels besides those measured directly can be obtained from such signatures by interpolation or extrapolation. Thus, results obtained at a given test site can be used to predict building response levels in similar structures subjected to other noise levels. This method of describing the noise/vibration relationship does not rely on measurements of maximum response levels with the associated statistical difficulty which results from necessarily small sample sizes. Also, the precise location of the noise source is not essential to this method as would have been the case if the building response was defined only in terms of maximum levels.

The noise and vibration measurements made in New York were augmented by limited subjective tests to examine the human detection/annoyance thresholds for building vibration and rattle caused by aircraft noise. The objective of these tests was to develop a method for determining the building vibration detection threshold and the minimum aircraft noise level associated with that threshold. The subjective tests were in the nature of a pilot program, with more emphasis on developing and refining the test method than on obtaining the kind of precision results which would require large numbers of test subjects to achieve. Nevertheless, this pilot study yielded results which are believed to bracket the human vibration detection threshold and which indicate approximate noise levels required to induce building vibrations that are detectable by human beings.

RESULTS AND DISCUSSION

Physical noise and vibration data acquired in this program were analyzed in terms of levels and signatures. Subjective data were analyzed in an attempt to determine detection threshold levels for building vibration.

Noise and Vibration Levels

Vibration measurements were made on the floors of the structures tested, as well as the walls and windows. Floor vibration levels were generally not large enough during a complete flyover to define a vibration/noise signature, however, peak levels were high enough to be uncontaminated by ambient levels and are presented in figure 2, along with peak noise levels and peak vibration levels for the windows and walls of several test structures. Noise and vibration levels for Concorde and conventional aircraft can be compared in this figure, and the vibration levels induced by aircraft noise can be compared with peak vibration levels induced by common domestic (nonaircraft) events such as walking inside and closing doors and windows.

Vibration levels caused by aircraft flyovers and common household events can also be compared in figure 2 with the detection threshold for floor vibrations and the vibration levels which would be expected to result in structural damage to walls and windows (broken windows, cracked plaster, etc.). This damage limit is calculated assuming a sinusoidal velocity of 1-inch per second for the frequencies contained within a 1/3-octave band centered at 200 Hz. The 200 Hz band was selected for this calculation because representative wall and window vibration spectra typically peaked at or near this frequency. A 1-inch per second velocity was used in the damage limit calculation because this value is accepted as the safe structure limit for vibration events lasting several seconds (ref. 1).

Vibration/Noise Signatures

For a given structural element, the response signatures were remarkably similar for all aircraft tested and, in particular, the Concorde response signatures were not distinguishable from the response signatures of the conventional aircraft types tested. This result suggests that source characteristics do not make Concorde an inherently more efficient generator of building vibrations. Higher vibration levels which may be observed during Concorde operations are attributed more to the higher overall noise levels of Concorde than to other unique source characteristics.

Similarities in response signatures at different test sites were also observed. Composite response signatures for three houses in the JFK area are superimposed in figure 3 to illustrate this similarity. Each signature is composed of data from several flyovers of different aircraft types. The width of each signature represents the scatter in the data comprising that signature. Note that the signatures from different test sites overlap considerably; that is, site-to-site response variations to a given aircraft noise level are generally no greater than the variations observed from flyover-to-flyover at a given test site. This similarity between test sites may be due to standardized construction details (wall stud and floor joist size and spacing, window and door size, etc.) which characterized the residential structures tested in these studies.

The similarity in the response signatures for Concorde and conventional aircraft can further be explained by examining the spectral characteristics of the aircraft noise. Such a comparison was made in ref. 9 where it was shown that the spectral shapes of Concorde and conventional aircraft are similar at the lower frequencies. This result, together with the similarity observed

between the response signatures of Concorde and conventional aircraft, suggests that building response to aircraft noise depends more on level than on other source characteristics.

The heavy lines in figure 3 represent composite window and wall response signatures for the residential structures tested. (Floor vibration levels were generally not large enough to define a vibration/noise signature.) Each signature encompasses a number of flyovers of several subsonic and supersonic aircraft over multiple test sites. It is believed that response signature variations among aircraft types and from site-to-site are sufficiently small to warrant this single signature representation. The equation for the window and wall response signature is as follows:

$$g = 10^{[(aS + b)/20]} - 6$$

where g is the acceleration in g's, S is the unweighted outdoor sound pressure level in dB relative to 20 micropascals, and the quantities a and b are the slope and ordinate intercept of the response signature. For windows and walls, a and b have the following values:

Parameter	Structural Element	
	Window	Wall
a	1.15	0.99
b	-16.50	-18.13

It can be shown that for the simple case of a mass-dominated response (i.e., neglecting damping and stiffness terms), the slope of the response signature has a theoretical value of one and for a given noise, the ordinate intercept depends on the area density of the structural element, being larger for structural elements with lower area density.

Detection Threshold

The noise and vibration measurements made in New York were augmented by limited subjective tests to examine the human detection/annoyance thresholds for building vibration and rattle caused by aircraft noise. The objective of these tests was to develop a method for determining the building vibration and rattle detection thresholds and the minimum aircraft noise level needed to exceed those thresholds.

The subjective response tests of vibration and rattle included both Concorde and a variety of subsonic aircraft operations. The tests were designed to obtain vibration and rattle thresholds, where threshold is defined as a positive (detection) rating by 50 percent of the subjects. The tests were conducted utilizing four members of the NASA monitoring team and the residents at each test site. Only the data obtained from the NASA subjects have been analyzed, since the residents experienced difficulty in differentiating between noise, vibration, and rattle due to the aircraft flyovers.

A total of 109 aircraft flyovers at eight sites in the JFK area were assessed for vibration and rattle. (Since rattle was detected by half the subjects on only three occasions, no further analyses have been undertaken of the rattle detection data.) For the vibration detection task, the subjects usually sensed the vibration of the floor either through the chair in which they were sitting or through their feet. After various noise and vibration measures were correlated with the judgments of vibration detection, indoor sound pressure level and floor acceleration level were found to be the best predictors, whereas the peak outdoor sound pressure level and the wall and window acceleration levels were found to be poorer predictors of vibration detection.

Figure 4 presents the percentage of the subjects that detected vibration as a function of the maximum vertical floor acceleration level. The threshold vertical floor acceleration level is seen to be about 68 dB in this figure. Floor vibration levels of this magnitude or higher were observed when the outside sound pressure levels were in excess of about 100 dB. Although not shown in the figure, there were no apparent differences between the judgments made at different test sites or for different aircraft types.

The judgments of vibration detection were compared with the ISO criterion by applying a weighting to the vertical acceleration spectra equivalent to a low-pass filter having a corner frequency of 8 Hz and an attenuation of 2 dB per 1/3-octave (curve 1, ref. 10). The maximum ISO-weighted acceleration levels were related to the judgments of vibration detection and the threshold value (54 dB vertical) agreed well with the ISO standard for hospital operating theaters and other critical areas.

CONCLUDING REMARKS

Aircraft noise and building vibration measurements were made at Sully Plantation, a restored 18th century farmhouse adjacent to Dulles International Airport, and at three homes in Montgomery County, Maryland. Similar measurements were made in New York on eight homes and a school near John F. Kennedy International Airport. These data were acquired between May 1976 and February 1978 in support of the Federal Aviation Administration's Concorde environmental impact assessment. Results of this study are as follows:

1. Representative values of peak aircraft noise-induced acceleration levels for typical structural elements of the homes tested are as follows:

windows	0.1 g - 1.0 g
walls	0.01 g - 0.1 g
floors	0.001 g - 0.01 g

2. Ordinary household events which involve direct impulsive loading of a given structural element often result in acceleration levels greater than those induced by aircraft noise.

3. Comparison of vibration response levels during aircraft operations with structural damage criteria shows the measured responses to be less than those expected to cause damage such as cracked plaster or broken windows.

4. The vibration response of building elements consisting of windows, walls, and floors is directly proportional to the unweighted sound pressure level of the aircraft noise and for a given noise level is virtually independent of aircraft type.

5. At a given noise level, Concorde induces no higher acceleration levels in a given structural element than subsonic aircraft. Higher response levels which may occur during Concorde operations are attributed more to higher Concorde noise levels than to unique Concorde source characteristics.

6. A method for determining the detection threshold for noise-induced building vibration has been successfully demonstrated in a pilot study. Results of this study indicate that the threshold for human detection of floor acceleration lies in the range of from 0.001 to 0.005 g's and that an outdoor noise level in excess of about 100 dB (unweighted) is required to induce this threshold response level.

7. The measured detection threshold for ISO-weighted floor acceleration levels agreed well with the ISO standard for hospital operating theaters and other critical areas.

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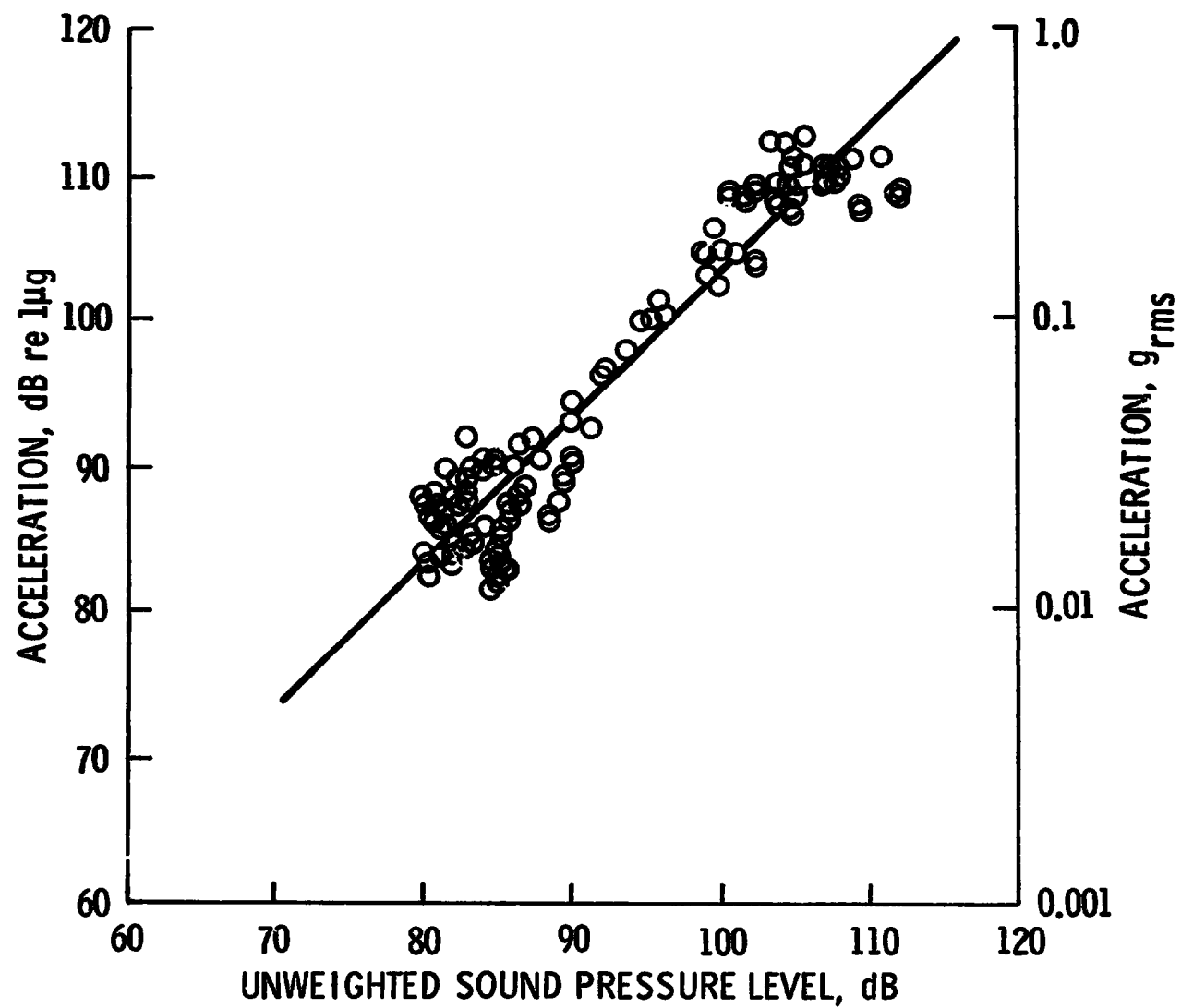


FIGURE 1.- REPRESENTATIVE WINDOW VIBRATION/NOISE RESPONSE SIGNATURE FOR CONCORDE TAKEOFF.

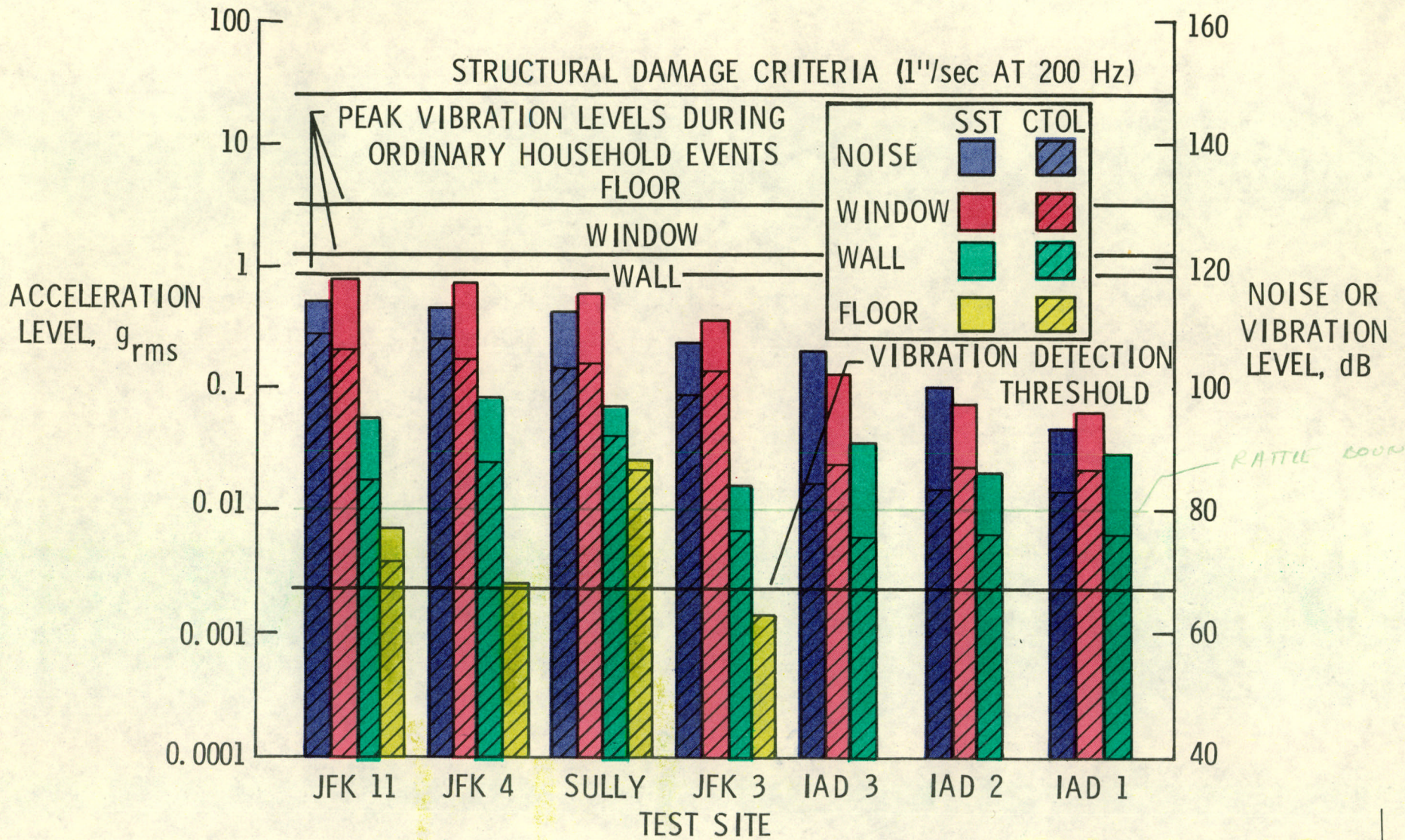


Figure 2. - Maximum noise and vibration levels recorded near Dulles and JFK airports.

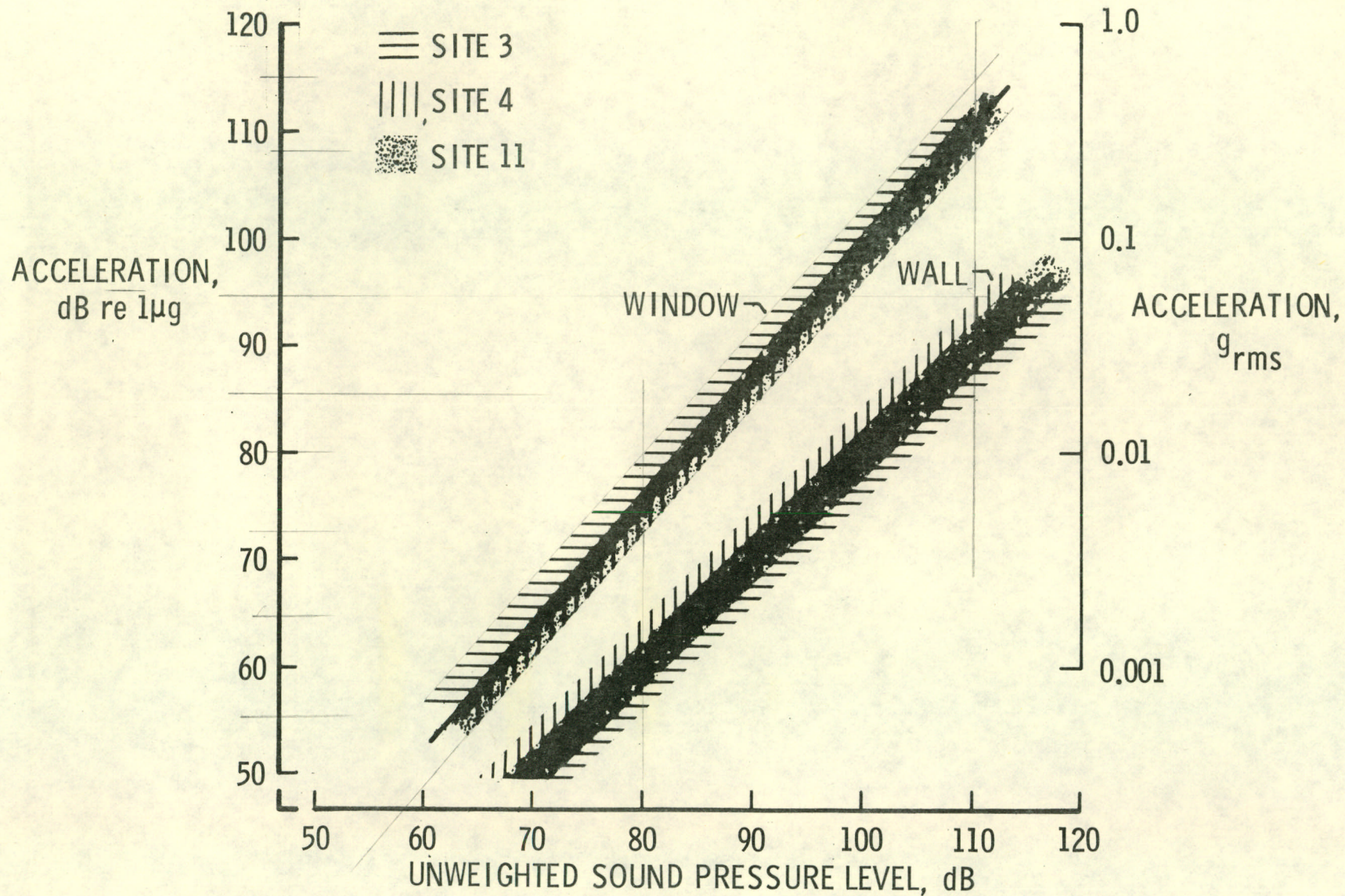


FIGURE 3.- COMPOSITE WALL AND WINDOW SIGNATURES FOR RESIDENTIAL STRUCTURES NEAR JFK.

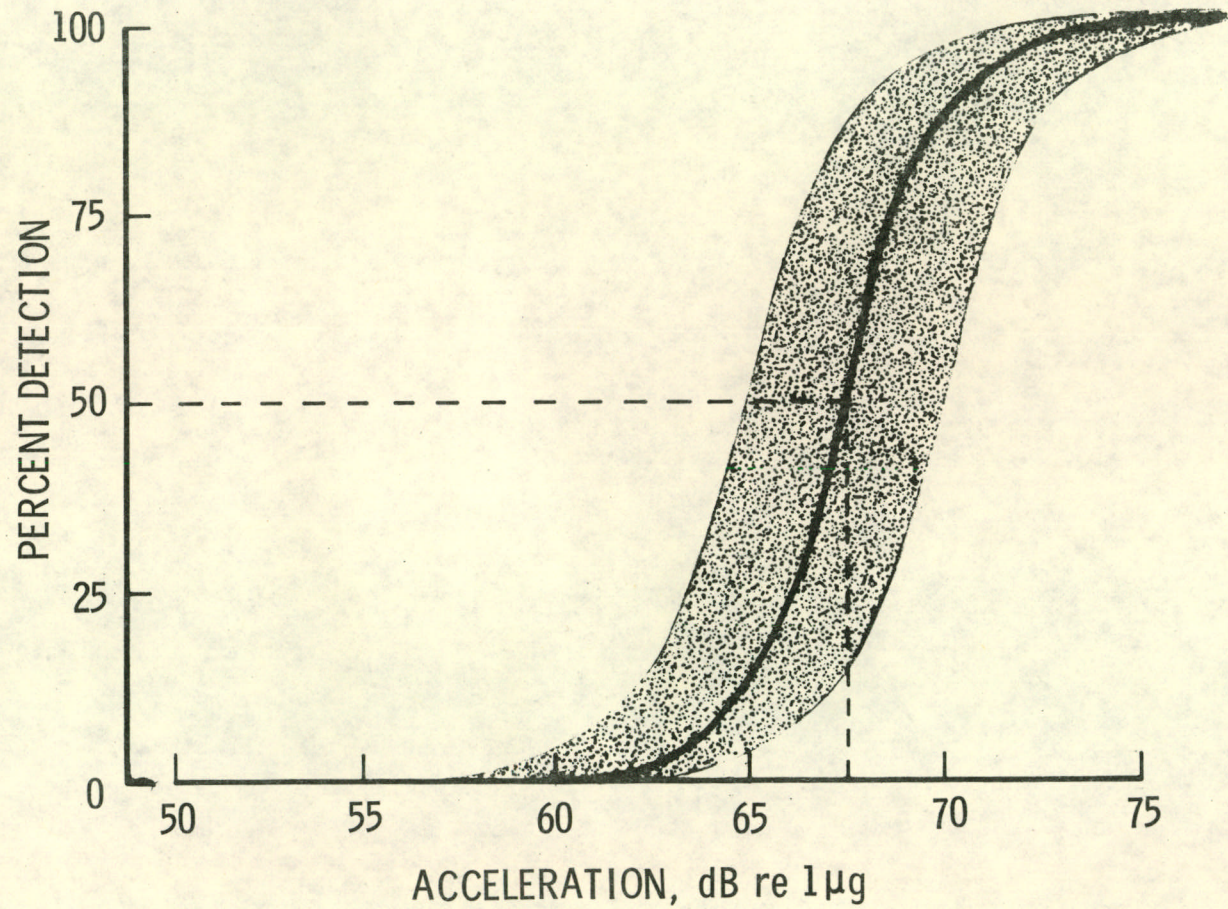


FIGURE 4.- DETECTION THRESHOLD FOR VERTICAL FLOOR ACCELERATION.