# 39. HOUSE VIBRATIONS SIGNIFICANT FOR INDOOR SUBJECTIVE RESPONSE

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## SUMMARY

An aircraft flyover is observed by a person inside a house in three ways: the acoustic transmission through the structure, the vibrations of the structure, and the noise radiated by decorative objects in contact with the structure. The average house structure provides from about 10 to 25 dB of noise reduction in the frequency range of 30 to 3000 Hz. The house vibration responses at the lower frequencies are associated with the framing members, whereas the vibration responses at the higher frequencies are associated with the window and wall panels. The indoor noise and vibration levels due to aircraft flyovers are of the same order of magnitude as those associated with rail and road traffic and normal household activities.

## INTRODUCTION

One aspect of the aircraft noise problem involves people inside houses. The dynamic response of the house structure is important because it affects both the noise and vibration stimuli of the observers inside the house. The nature of the noise-induced house-structure response problem is illustrated schematically in figure 1. The aircraft noise excitation is evident to a person inside the house by means of three different phenomena. He hears the noise transmitted through the building walls; he can sense directly the vibrations of the various components of the house such as walls and ceilings; and he can hear the radiated noise from objects such as shelves, dishes, and ornaments, set in motion by the vibration of the walls with which they are in contact.

A programed overflight was conducted to study these phenomena at the NASA Wallops Station. Vibration response and noise transmission characteristics of two houses were investigated. The purpose of this paper is to discuss the results from this study for each of the three phenomena for aircraft noise excitation and to compare the associated responses with those from other noise sources.

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## EXPERIMENTAL STUDIES

Two of the houses used in aircraft noise reduction studies are shown in figure 2. One house was of brick-veneer construction with a concrete-slab foundation and steel casement windows; the other was of aluminum-siding construction with a cinder-block foundation and double-hung windows. Both houses were one-story six-room structures and had asphalt-shingle roofs with interior construction of sheet rock with plaster.

The houses were fully furnished and during test operations all windows and external doors were closed. Data were obtained for 10 different aircraft during flyovers at simulated landing approach and climbout thrust conditions at various altitudes.

### Noise Reduction

An example of the manner in which the inside noise is related to the outside noise for the aluminum-siding house is shown in figure 3. One-third octave band spectra are plotted for measurement locations both inside and outside the house. These particular spectra are for a turbofan aircraft in the landing approach condition, It is obvious that the two spectra differ in several respects and that these differences result from the influences of the structure. A dominant feature of each spectrum, however, is a strong peak at about 2000 Hz. These peaks are associated with discrete-frequency noise from the fan sections of the engines. The differences between these two spectra indicated by the hatched region represent the noise reductions supplied by the structure at various frequencies. Noise reduction is plotted as a function of frequency in figure 4.

Noise reductions due to the house are seen to vary considerably with frequency. These variations with frequency are believed to be associated with the vibrational characteristics of the structure which are discussed subsequently in more detail. The average noise reduction increases generally as a function of frequency and varies from about 5 dB at the lower frequencies to about 20 dB at the higher frequencies, for this particular house.

A summary of the noise reduction data from this and other studies is included in figure 5. The range of noise reductions obtained in the present study is represented by the data between the solid curves. Similar data recorded in houses on the East Coast, the West Coast, and the Gulf Coast by other investigators (refs. 1 and 2) are included for comparison and are represented by the area between the dashed curves. The data of the present study overlap those of the previous studies; this suggests that the noise reduction characteristics of the test houses of figure 2 were roughly similar to those of houses in other regions of the country. The average noise reduction for all houses considered varies from about 10 dB to 25 dB in the frequency range of 30 to 3000 Hz.

The noise reduction of a house is believed to be a function of several variables such as type of construction, size and style, furnishings, windows and doors, workmanship, condition of materials, and age. Each of these may under certain circumstances be significant. In spite of the existence of many differences between houses, there also exist many similarities in dynamic behavior because of the common usage of standard size components such as beams, rafters, wall panels, and windows,

## Vibration Responses

A series of experiments has been conducted to define the dynamic response characteristics of house components and to evaluate their responses to aircraft noise. One of the experiments involved the use of a mechanical shaker, as illustrated in the sketch of figure 6, to excite the structure with a sinusoidally varying load at a point on the wall for the purpose of defining its dynamic response characteristics. During these experiments the input force was varied both in frequency and in magnitude to study various response modes of the structure. The associated acceleration responses as functions of the input force are shown in figure 6 for one of these response modes at a frequency of 100 Hz. Acceleration response increases in a linear manner as the input force increases. Similar results were obtained for a range of response modes and for several different measurement locations.

During forced vibration tests, about a 2-pound force from the shaker resulted in vibrations over a large portion of the house which were of the same order of magnitude as those observed during aircraft flyovers. These results suggest that over the range of interest for aircraft-induced vibrations, the house structures behave essentially in a linear manner.

An example of the types of data obtained for a constant force input of a shaker as a function of frequency for the aluminum-siding house is shown in figure 7. Several response peaks can be seen in the acceleration spectrum of figure 7. Probe transducer surveys have made possible the definition of the mode shapes associated with many of these frequencies. Mode shapes for four vibration modes associated with the peaks labeled A, B, C, and D in figure 7 are shown in figure 8. The vibration modes of the building below approximately 100 Hz were associated mainly with the framing members such as wall studs and floor joists. Similar low-frequency response spectra have been obtained for many different houses. This similar response may be expected since houses are customarily built with standard size framing members.

No attempt was made to define in detail the mode shapes for the high-frequency portion of the spectrum of figure 7; such high-frequency modes involved mainly the window and wall panels. This general result for many houses is probably associated also with the use of standard size window and wall panels in house construction.

From a subjective reaction standpoint, high-frequency noise transmitted through the structure can be important; therefore, modifications to a house structure to attenuate high-frequency noise would involve considerations of the window and wall panels. Another source of high-frequency noise is the vibration and rattle of ornaments and fixtures attached to or in contact with a wall; this is a result of low-frequency wall motions. When the wall motions reach a given amplitude, such objects will vibrate at frequencies higher than the wall frequencies and in a range readily observable as rattles.

### Noise-Induced Rattle

A specific example of a rattle situation involving wall mounted plaques is illustrated in figure 9. Wall acceleration level as a function of frequency is given for two types of excitation. The solid curve with hatching represents a rattle boundary established by tests with the use of a mechanical shaker, illustrated in the sketch. For wall accelerations exceeding those of the boundary at the frequencies indicated, the plaques will rattle in an annoying manner. Shown for comparison is an acceleration spectrum measured at the same instrument location for an aircraft flyover. The aircraft-noise-induced accelerations exceeded those of the rattle boundary and the plaques rattled. Such a rattle situation is a classical example of nonlinear dynamic responses where the excitation of a structure by one frequency results in responses at a different frequency.

## COMPARISON OF VIBRATION AND NOISE LEVELS FROM AIRCRAFT AND OTHER SOURCES

A comparison of the wall vibration levels of houses due to aircraft noise with vibrations as a result of other common events is given in figure 10. The bars indicate the ranges of wall acceleration level for each of the events listed. Also indicated, as a matter of interest, are the vibration levels associated with perception and onset of annoyance from experience with continuously operating rotating machinery (ref. 3). Comparable perception and annoyance levels €or flyover noise-induced transients have not yet been defined. The aircraft-noise-induced vibrations are of the same order of magnitude as those associated with rail and road traffic and normal household activities; acceleration levels associated with loud hi-fi operations are the most severe to which house structures are exposed.

Similar results are presented in figure 11 for the indoor noise levels associated with the same events of figure 10. The sound pressure levels from all these events exceed normal speech levels; hence, occasional speech interference would be encountered. The highest sound pressure levels were associated with loud hi-fi operations.

## CONCLUDING REMARKS

An aircraft flyover is observed by a person inside a house in three ways: the acoustic transmission through the structure, the vibrations of the structure, and the noise radiated by decorative objects in contact with the structure. The average house structure provides from about 10 to 25 dB of noise reduction in the frequency range of 30 to 3000 Hz. The house vibration responses at the lower frequencies are associated with the framing members, whereas the vibration responses at the higher frequencies are associated with the window and wall panels. The indoor noise and vibration levels due to aircraft flyovers are of the same order of magnitude as those associated with rail and road traffic and normal household activities.

## REFERENCES


1. Anon.: Methods for Improving the Noise Insulation of Houses With Respect to Aircraft Noise. Rep. 1387 (Contract FH-941), Bolt Beranek and Newman Inc., Nov. 1966.
2. Bishop, Dwight E.: Reduction of Aircraft Noise Measured in Several School, Motel, and Residential Rooms. J. Acoust. Soc. Amer., vol. 39, no. 5, May 1966, pp. 907-913.
3. Rathbone, Thomas C.: Human Sensitivity to Product Vibration. Prod. Eng., vol. 34, Aug. 5, 1963, pp. 73-77.

## NATURE OF THE PROBLEM

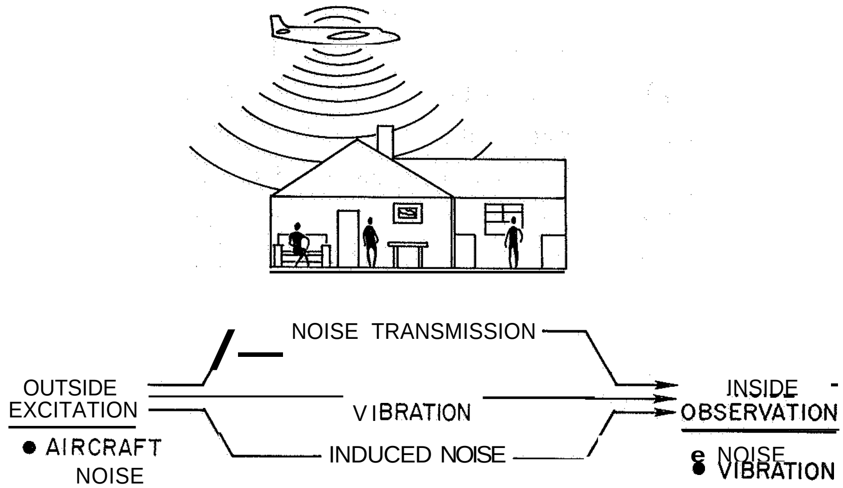
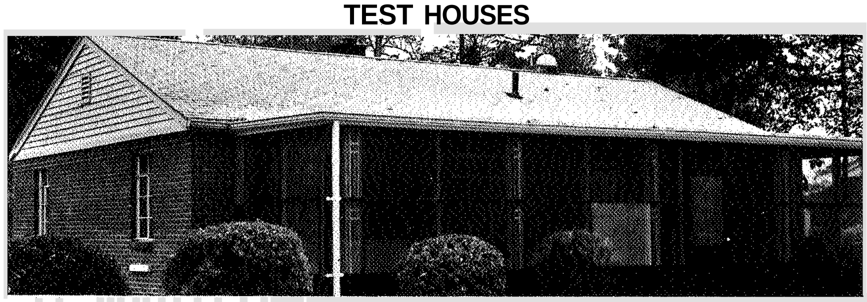



Figure 1

## TEST HOUSES



BRICK VENEER

ALUMINUM SIDING

L-68-8586

Figure 2

EXAMPLE OF AIRCRAFT NOISE SPECTRA

ALUMINUM SIDING

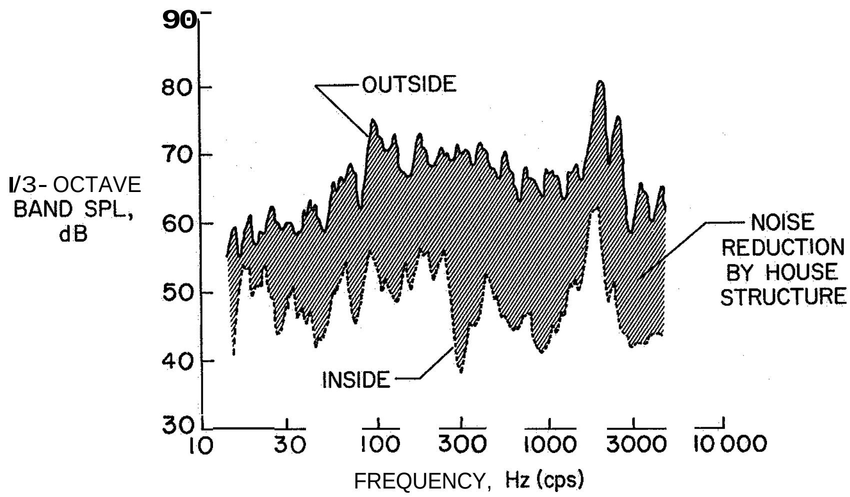



Figure 3

NOISE REDUCTION BY HOUSE STRUCTURE

ALUMINUM SIDING

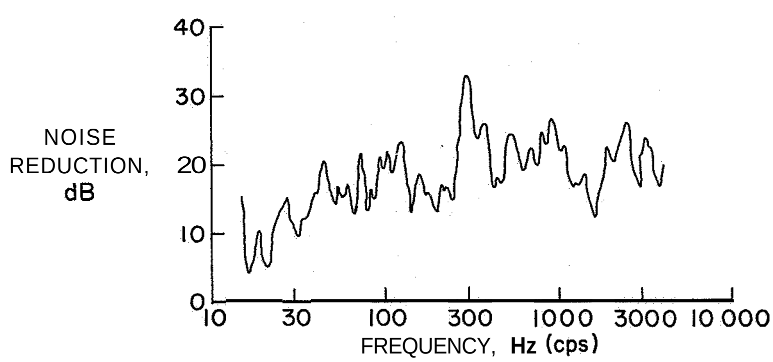



Figure 4

SUMMARY OF NOISE REDUCTION BY HOUSE STRUCTURES

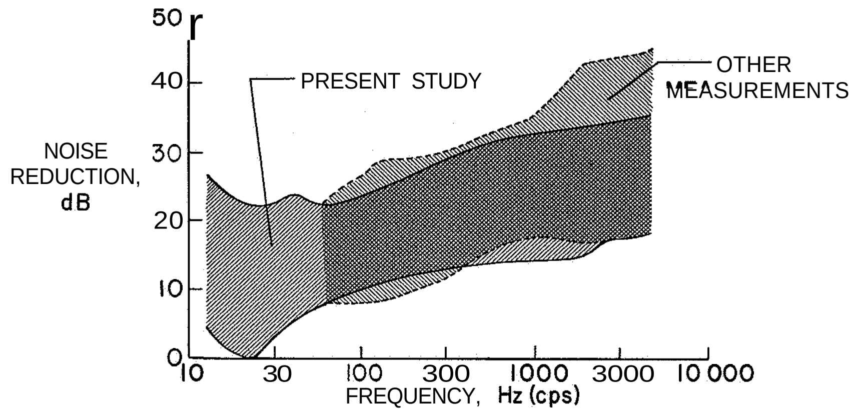



**Figure** 5

WALL ACCELERATION RESPONSES

MECHANICAL EXCITATION; FREQUENCY = 100 Hz

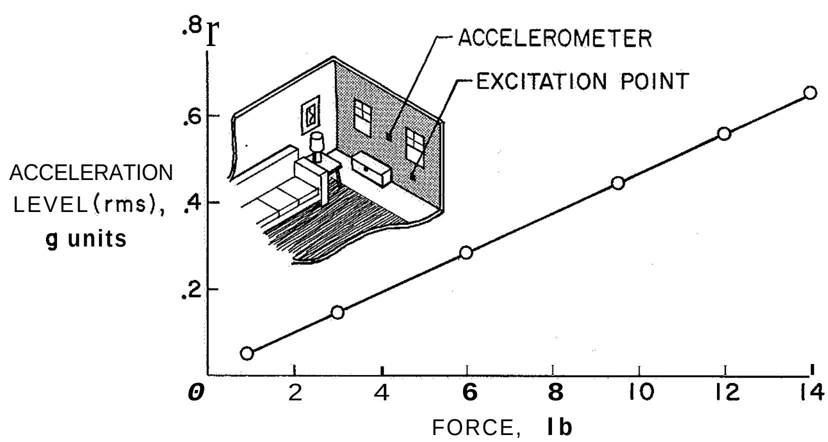



**Figure 6**

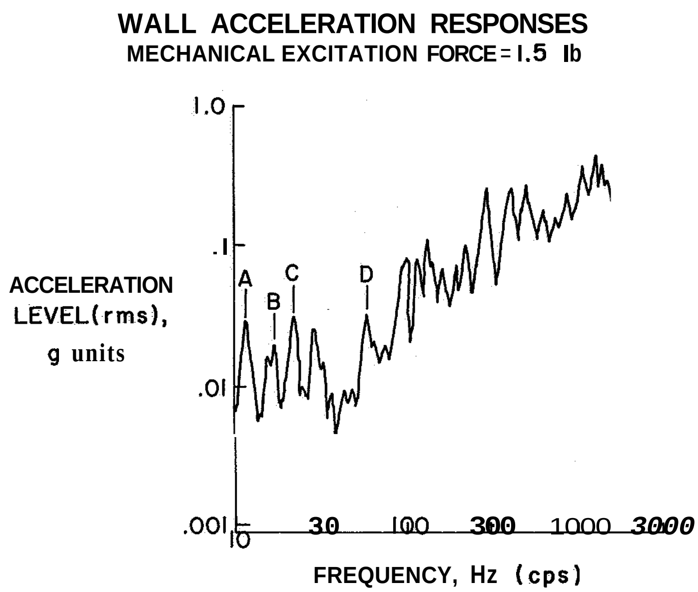



Figure 7

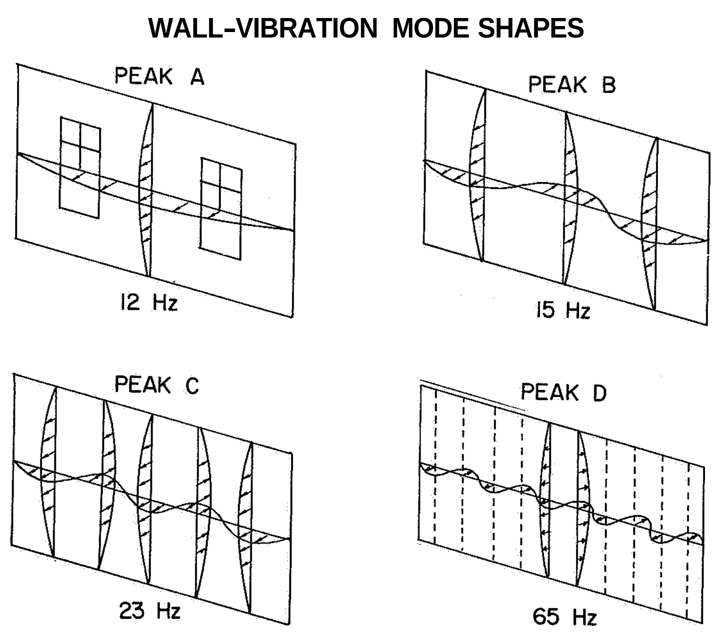



Figure 8

EXAMPLE OF RATTLE

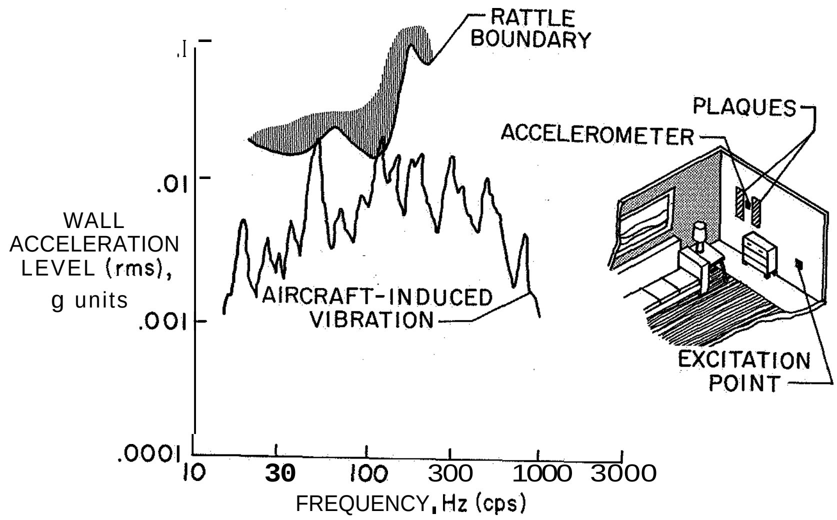



Figure 9

MEASURED INDOOR VIBRATION LEVELS

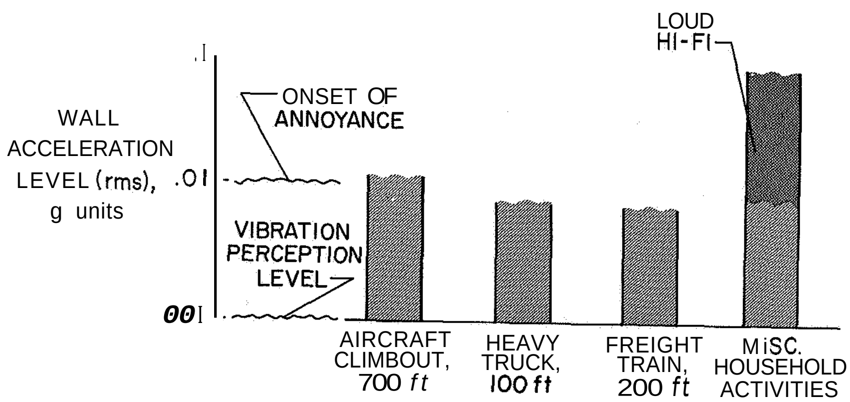



Figure 10

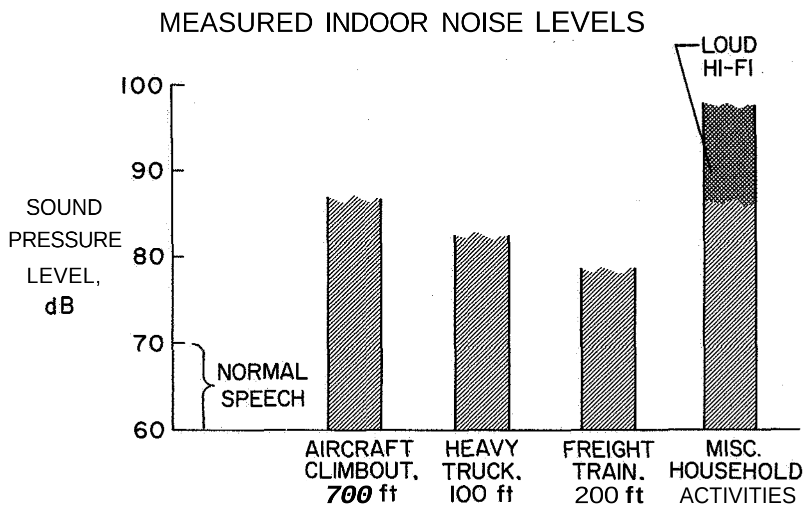

MEASURED INDOOR NOISE LEVELS
LOUD HI-FI
100
90
80
70
60
SOUND PRESSURE LEVEL, dB
NORMAL SPEECH
AIRCRAFT CLIMBOUT, 700 ft
HEAVY TRUCK, 100 ft
FREIGHT TRAIN, 200 ft
MISC. HOUSEHOLD ACTIVITIES

Figure 11



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