NASA Technical Memorandum 104170

BUILDING VIBRATIONS INDUCED BY NOISE FROM ROTORCRAFT AND PROPELLER AIRCRAFT FLYOVERS

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N92-33160

Unclas

JUNE 1992

(NASA-TM-104170) BUILDING VIBRATIONS INDUCED BY NOISE FROM ROTORCRAFT AND PROPELLER AIRCRAFT FLYOVERS (NASA) 29 p

National Aeronautics and Space Administration

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SUMMARY

Noise and building vibrations were measured for a series of helicopter and propeller-driven aircraft flyovers at NASA-Wallops Flight Facility, Wallops Island, Virginia during May 1978. The building response data are compared with similar data acquired earlier at sites near Dulles and Kennedy Airports for operation of commercial jet transports, including the Concorde supersonic transport. Results of this study show that noise-induced vibration levels in windows and walls are directly proportional to sound pressure level and that for a given noise level, the acceleration levels induced by a helicopter or a propeller-driven aircraft flyover cannot be distinguished from the acceleration levels induced by a commercial jet transport flyover. Noise-induced building acceleration levels were found to be lower than those levels which might be expected to cause structural damage and were also lower than some acceleration levels induced by such common domestic events as closing windows and doors.

INTRODUCTION

The vibration of buildings due to aircraft noise and the associated potential for structural damage and human annoyance have been the subject of public concern, as evidenced by the frequency with which building vibration complaints have appeared in the results of social surveys investigating the impact of aircraft flyover noise (refs. 1,2, 3). This concern intensified in the United States with the introduction of the Concorde supersonic transport (SST) at Dulles and Kennedy Airports (refs. 4, 5) Consequently aircraft noise and building responses were measured in neighborhoods surrounding Dulles and Kennedy Airports between May 1976, and March 1978 to compare the structural responses of buildings resulting from SST operations with those of conventional jet transports (ref. 6-14). In May of 1978, a rotorcraft and propeller aircraft flyover test was conducted at the NASA Wallops Flight Facility to assess subjective response to noise with varying degrees of impulsiveness (ref. 15). The opportunity was taken during the Wallops Flight Facility tests to gather additional building vibration data to augment the data base obtained during the Dulles and Kennedy tests referred to above.

This report presents noise and building vibration data acquired during the Wallops Flight Facility tests. The responses of windows and walls to noise from rotorcraft and propeller aircraft are compared with similar results obtained during the Dulles and Kennedy tests, which involved conventional jet transports and the SST. Responses due to noise from all aircraft types tested are compared with vibrations caused by ordinary household events recorded in the Dulles and Kennedy tests, such as the closing of doors and windows. Relationships between aircraft noise and building response are presented, as are peak measured levels of aircraft noise, noise-induced vibrations, and vibrations due to common household events.

APPARATUS AND METHODS

Test Aircraft

A propeller-driven airplane (North American T-28) and two helicopters (Bell 204B and Bell OH-58A) were used as noise sources (fig. 1(a), (b), (c)). The helicopters were chosen to satisfy a requirement for varying degrees of impulsiveness. Previous experience indicated that the noise signature of the Bell 204B is typically very impulsive, due to its high tip speed and relatively large blade chord. However, this impulsiveness could be changed by varying the rotor blade tip speed while maintaining a constant airspeed. The Bell OH-58A generated much less impulsive noise than the 204B because of its lower tip speed. Since the lower tip speed also limits possible variation in its impulsive noise characteristics the OH-58A was flown with a constant rotor speed.

A T-28A single-engine, propeller-driven, fixed-wing airplane (figure 1(a)) was selected to provide "nonhelicopter" noise conditions. It was flown at a speed of 58 m/s for the series of comparison flights so that the durations of noises would be similar to those for the helicopters. Extended landing gear, full flaps and maximum climb power were used to maintain this comparatively low speed and still produce sufficient noise levels. Selected characteristics of each of the aircraft used in the tests are given in table I, from reference 15.

Test Site and Structures

The test site selected for the experiments was the NASA Wallops Flight Facility. This selection was based on considerations of control of airspace, control of background noise, availability of proper tracking facilities, and availability of unoccupied houses for indoor testing. Two houses were selected which were of different construction and orientation to the flight paths and which were in line with an open area for use by the outdoor subject groups. House K-3 (figure 2(a)) was of brick veneer construction and house K-25 (figure 2(b)) was of frame construction with aluminum siding. Both were single story and had concrete slab floors. The orientations of the houses to the flight paths are shown in figure 3. Although data were obtained for heights and distances other than those shown in figure 3, the flights for which data are included were at an altitude of 90 m and were either directly over the houses or were displaced 120 m toward the west.

Noise Excitations

The noise excitations incident on the structures are illustrated in figure 4. Typical A-weighted sound pressure level time histories are shown for all three aircraft and for the conditions of the tests. Also included are the corresponding sound pressure signatures. Note that the 204B noise is dominated by the main rotor blade passage frequency of about 10-11 Hz. depending on the operational rotor rpm. The

OH-58A noise on the other hand is dominated by the tail rotor which has a blade passage frequency of about 88 Hz. The T-28 noise is dominated by the second harmonic (160 Hz) of the blade passage frequency.

Instruments, Measurements and Analyses

Measurements of both interior and exterior sound pressure levels were recorded with special low-frequency response microphones used for the interior measurements. Vibration data were obtained from piezoelectric crystal accelerometers mounted on the window and from more sensitive, but heavier, servoaccelerometers mounted on the wall. Noise and vibration data were recorded simultaneously on FM instrumentation tape recorders along with time code and voice annotation.

Extensive pretest calibration of each channel of the data acquisition system was performed to measure frequency response, gain accuracy, and dynamic range. Daily calibrations in the field consisted of pink noise (exhibiting flat 1/3-octave band spectrum level) insertion in all microphone channels, a fixed sine wave reference voltage insertion into the accelerometer channels as well as a 1 g static calibration of the servoaccelerometers, and a 250 Hz piston-phone acoustic calibration of the microphone systems during pretest and posttest periods. The frequency response of the acoustic channels was nominally ± 1 dB over the range 5 Hz to 10 kHz for the exterior measurement systems and 1.5 Hz to 10 kHz for the lower frequency interior measurement systems. The frequency response of the accelerometer channels was nominally ±1/2 dB from DC to approximately 1 kHz for the servoaccelerometers and from 3 Hz to in excess of 3 kHz for the piezoelectric type.

When microphones and accelerometers attached to a structure are both exposed to the same noise field, the measured acceleration levels have been observed to increase linearly with sound pressure level (see refs. 4 and 9). If an acoustic shadow engulfs either the microphone or the accelerometer (for example during those portions of a flyover when lines of sight from the source to either transducer are interrupted or shadowed by part of the test house) it is possible for the measured acceleration to increase while measured noise levels decrease or vice-versa, depending on which transducer is shadowed. This differential loading effect, consistently observed in the Dulles and Kennedy Airport tests (refs. 6 and 10), complicates the analysis of the data somewhat by requiring that only those portions of a flyover be studied for which the noise and vibration levels are both increasing or are both decreasing. In the data presented in figures 5-8 of this report, accelerometer and microphone time histories were initially examined for evidence of shadow effects and only those portions of each flyover were analyzed for which both transducers had a clear line of site to the aircraft.

RESULTS AND DISCUSSION

Flight Path Effects

Preliminary analyses showed that flight path differences affected only the levels of recorded noise and vibrations; the relationship between noise and vibration described by the noise/vibration signatures was unaffected by flight path. This suggests that, at least for the range of geometries encountered in the tests reported here, the noise/vibration signature of a given flight vehicle does not depend strongly on the azimuthal angle of incidence. Because the vibration signal-to-noise ratios were relatively low for the more distant flight paths (especially for the wall acceleration measurements) and because the data revealed no significant effects attributed to flight path differences, only data for the two flight paths nearest the houses are presented in this report (the overhead and 120m sideline flight paths at an altitude of 90m).

Measured Window Accelerations

Data points presented in figures 5(a) and (b) comprise the responses for the windows of test houses K-3 and K-25 respectively, at the Wallops Flight Facility. The three symbol shapes represent the three test aircraft. Each point represents a simultaneous measurement of RMS outside sound pressure level and RMS acceleration. Although data were acquired in half-second intervals during each flyover, only every other data point is presented in the figure, to reduce clutter. The least squares linear fit lines for both sets of data are shown in figure 5. Note that the data points eliminated from figure 5 were still incorporated in the above least squares analyses. Data points exhibit a scatter of about ±5 dB about the least squares lines.

Figure 6 shows a comparison of window responses from the helicopter and propeller airplane flyover tests of Wallops with those from the Kennedy Airport, Dulles Airport and Sully Plantation tests involving the Concorde and other jet powered transport aircraft such as the 707, 747, DC-10, L-1011, 727 and DC-8. The straight lines are least squares lines from figures 5(a) and (b); and the shaded region encompasses the least squares lines for all the published data sets from the Kennedy and Dulles airport tests. The Dulles Airport data are taken from figures 6(a), (b), and (c) of ref 8; and the Kennedy Airport data are taken from figures A-1 to A-11 of ref. 11 and figures A1 to A4 of ref. 12. It can be seen that the Wallops test results are in general agreement with the comparable jet aircraft test results and that window acceleration levels are approximately linearly related to the outdoor sound pressure levels.

Measured Wall Accelerations

Corresponding wall acceleration measurements were analyzed in the same manner as for figure 5 and the results are presented in figure 7(a) and (b). Data are included for both K-3 and K-25 houses respectively and for excitation by all three aircraft. Note that as was found for the windows, the data exhibit a spread of about ±5 dB.

The least squares fit curves for the data of figure 7(a) and (b) are shown in figure 8, along with the comparable measured wall responses from Kennedy and Dulles Airport tests. The Dulles airport data are taken from figure 6 (d) (e) and (f) of ref. 8; and the Kennedy Airport data are taken from figures A-12 to A-33 of ref. 11 and figures A5 to A8 of ref. 12. Good agreement again is seen between the Wallops Flight Facility data and the response data for the Dulles and Kennedy tests.

General Observations

The data displayed in figures 5 and 7 represent a composite of several flyover events for each aircraft type. Response variations for a given aircraft type, for different flyovers, while not displayed explicitly in these figures, were found to be negligible. Scatter in the response data for multiple flyovers of a given aircraft type was not greater than the scatter for a single flyover. Similar consistency was also observed in the Dulles and Kennedy test results.

For any given noise level, there is substantial overlap in the acceleration levels produced by each aircraft type. That is, it is not possible to identify the aircraft type from the measured building vibration levels. In particular these data suggest that the impulsive nature of helicopter noise does not result in a significantly different building response than does noise from less impulsive sources such as commercial jet transports.

For the reader who may be interested in the peak values of the noise excitation, the crest factors (ratio of peak to RMS values) for the 204B and OH58A helicopters were measured to be 12.5 dB and 11.4 dB respectively. These values are somewhat larger than the value of 10 dB which is frequently ascribed to random noise and to the flyover noise of conventional jet powered aircraft.

Between-house response differences were not apparent. That is, variations in response from house to house were within the scatter in response associated with flights over a given house. Scatter in the response data for the windows and walls presented here is sufficiently great that the effects of response variations from aircraft type to aircraft type or from house to house are difficult to resolve. One cannot uniquely specify the type of aircraft or type of house construction from the acceleration levels induced in a house by a single aircraft flyover.

The vibration levels resulting from other noise levels besides those measured directly can be inferred from these data by linear 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. If however the acoustic excitation is markedly different, or the type of construction is markedly different, or both, the above results may not apply.

Maximum Noise and Acceleration Levels

Maximum noise and acceleration levels for each of the two test houses are presented in table II. Because of the shadow effect described earlier, the maximum noise and acceleration levels did not necessarily occur simultaneously.

Maximum noise and vibration levels measured during helicopter flyovers (labeled WFC) are compared in figure 9 with maximum noise and vibration levels measured near Dulles (IAD) and Kennedy (JFK) airports during takeoffs and landings of commercial jet transports, including the Concorde.

Vibration levels caused by aircraft flyovers and common household events such as closing of windows and doors, can also be compared in figure 9 with the detection threshold for floor vibrations (as determined in the Kennedy tests, ref. 13) 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 was 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 window vibration spectra typically peaked at or near this frequency and there was substantial wall response as well. 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. 5

Figure 9 indicates that building vibrations induced by flyovers of helicopters and commercial jet transports are well below the levels which would be expected to cause structural damage to walls and windows. Furthermore, common household events can result in structural vibrations which equal or exceed those induced by either helicopter or jet transport flyover noise.

Concluding Remarks

Noise and building vibration measurements have been made for a series of helicopter and propeller-driven aircraft flyovers conducted at NASA Wallops Flight Facility, Wallops Island, Virginia in May 1978. These data have been compared with similar data acquired earlier near Dulles and Kennedy airports during takeoffs and landings of commercial jet transports, including the Concorde. Principal findings of this study are:

1. As in the case of commercial jet transport flyovers, a linear relationship was found to exist between sound pressure levels and building acceleration levels induced during flyovers of the helicopters and propeller driven aircraft used in these tests.

2. For a given noise level, building vibration levels induced during helicopter and propeller-driven aircraft flyovers were found not to differ significantly from building vibration levels induced during commercial jet transport flyovers, despite the relatively more impulsive nature of the helicopter and propeller-driven aircraft noise.

3. Building vibration levels induced during the flyover tests reported here were substantially lower than the levels which would be expected to cause structural damage such as broken windows and cracked plaster.

4. Common household events which involve direct impulsive loading of a given structural element can result in building vibration levels which exceed those induced during flyovers of helicopters, propeller-driven aircraft, or commercial jet transports, including the Concorde.

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TABLE I. - TEST AIRCRAFT CHARACTERISTICS

Characteristic	Helicopter		Airplane
Manufacturer	Bell	Bell	North American
Model	204B	OH-58A	T-28A
Power plant	Lycoming T53	Allison T63	Wright R1 300-1
Type	Turboshaft	Turboshaft	7 cylinder radial
Rated output, kw	821 (1100 shp)	236 (317 shp)	597 (800 hp)
Maximum gross weight, kg	3864	1318	3072
Maximum air speed, m/s	62	62	129
Number of Blades			
Main rotor	2	2	----
Tail rotor	2	2	----
Propeller	----	----	2
Diameter, m			
Main rotor	14.63	10.16	----
Tail rotor	2.59	1.57	----
Propeller	----	----	3.05
Nominal rotor speed, rpm			
Main rotor	324	354	----
Tail rotor	1662	2624	----
Propeller	----	----	2400
Blade passage frequence, Hz			
Main rotor	10.8	11.8	----
Tail rotor	55.4	87.5	----
Propeller	----	----	80.0
Tip speed, m/s			
Main rotor	248	188	----
Tail rotor	225	216	----
Propeller	----	----	383

TABLE II. - MAXIMUM NOISE AND ACCELERATION LEVELS

AIRCRAFT TYPE	SITE					
	K - 3			K - 25		
	Noise Level, dB re $2x10^{-5}$Pa	Acceleration Level, dB re 1.0 μ G		Noise Level, dB re $2x10^{-5}$Pa	Acceleration Level, dB re 1.0 μ G	
		Window	Wall		Window	Wall
204 B	104.8	105.7	85.7	103.2	100.5	89.1
OH-58	90.5	90.5	74.1	91.7	85.2	75.2
T-28	101.2	99.5	80.5	101.0	103.6	89.6

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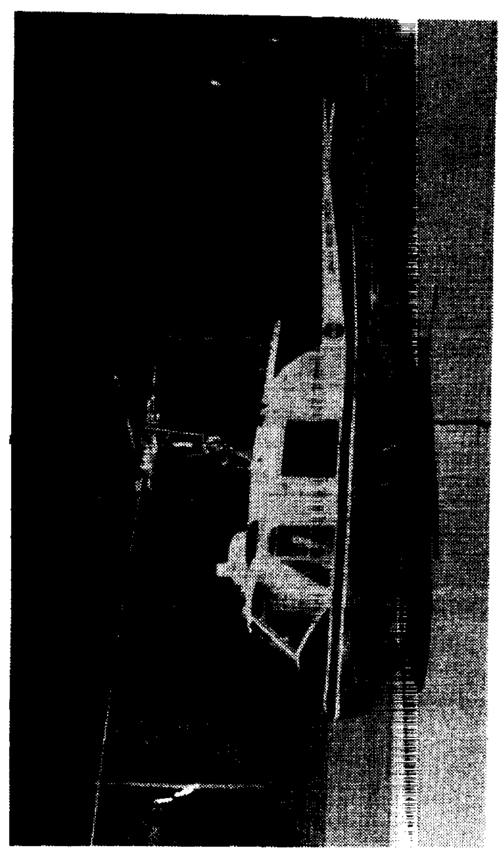
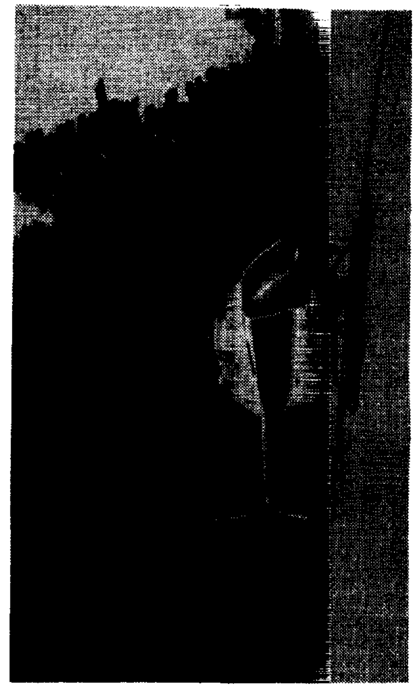
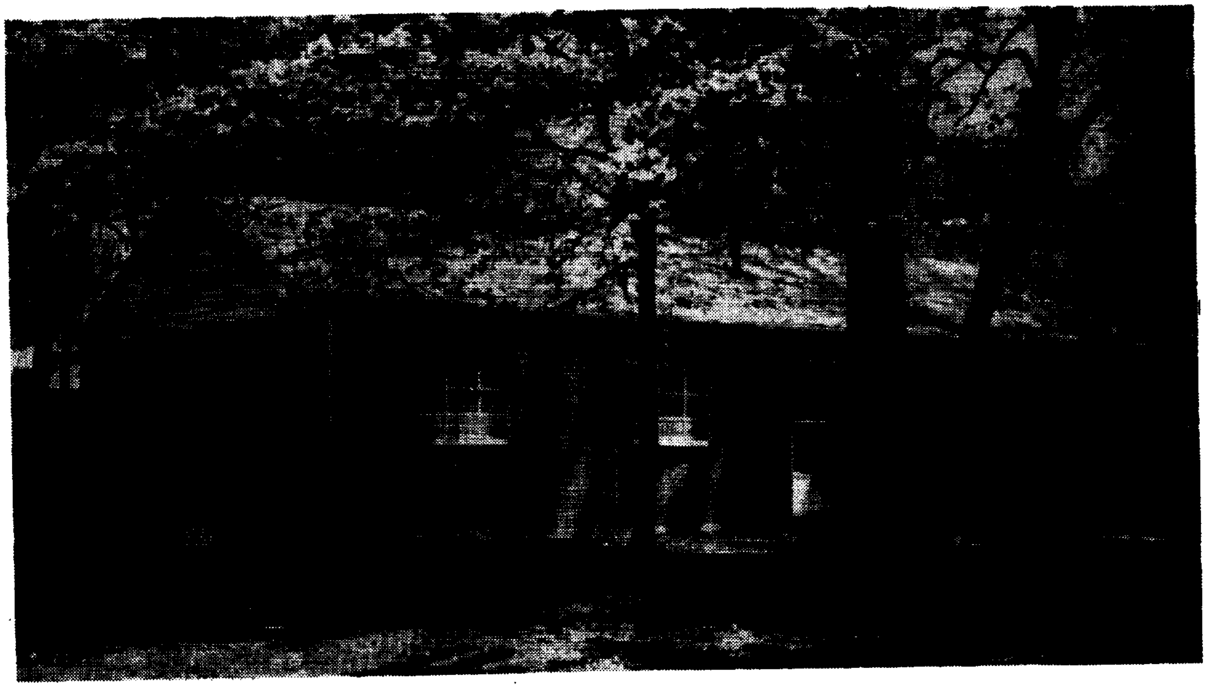
(a) North American T-28



(b) Bell 204B



(c) Bell OH-58A



(a) Brick veneer house (K-3)

(b) Wood frame house (K-25)

Figure 2. - Test structures

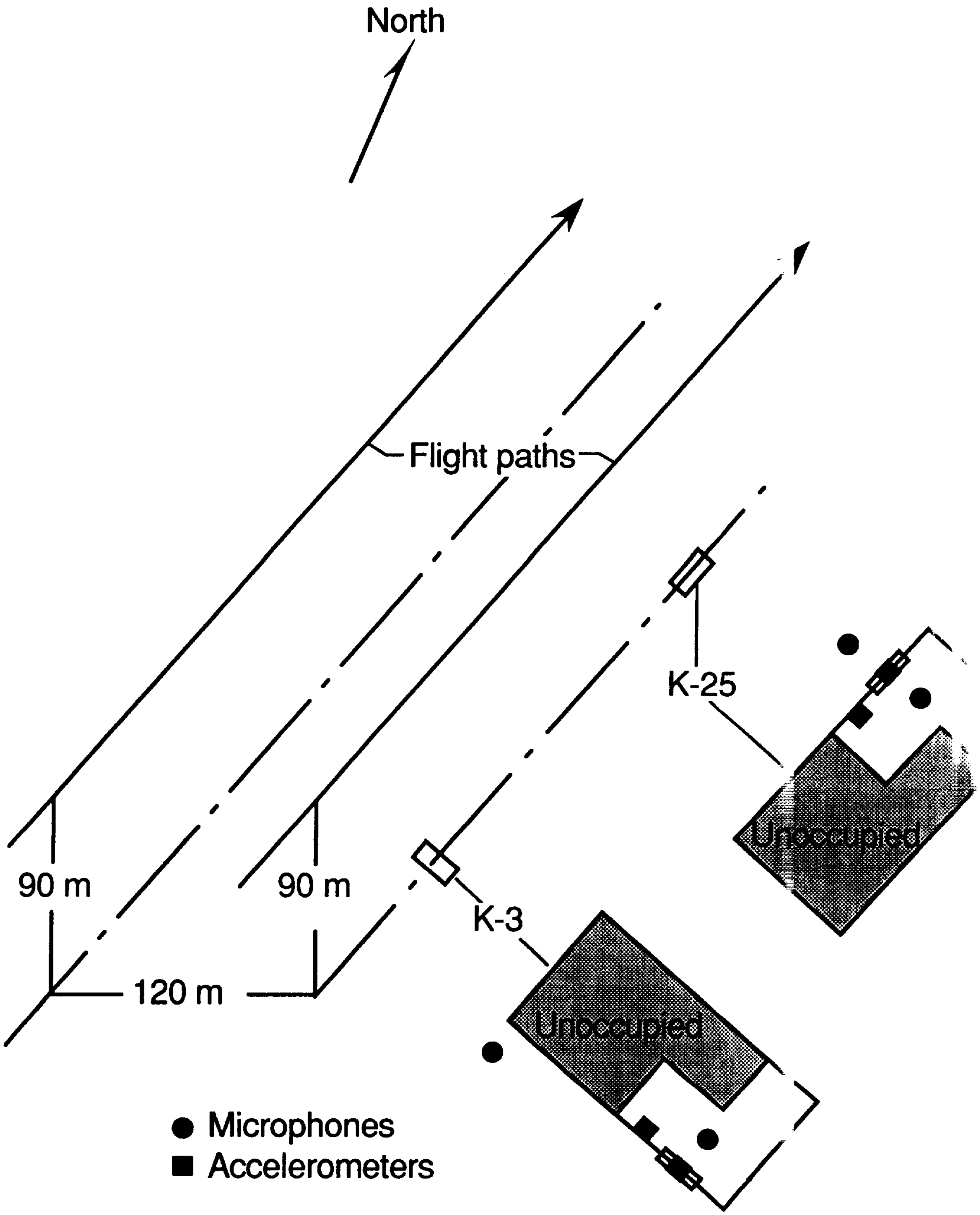
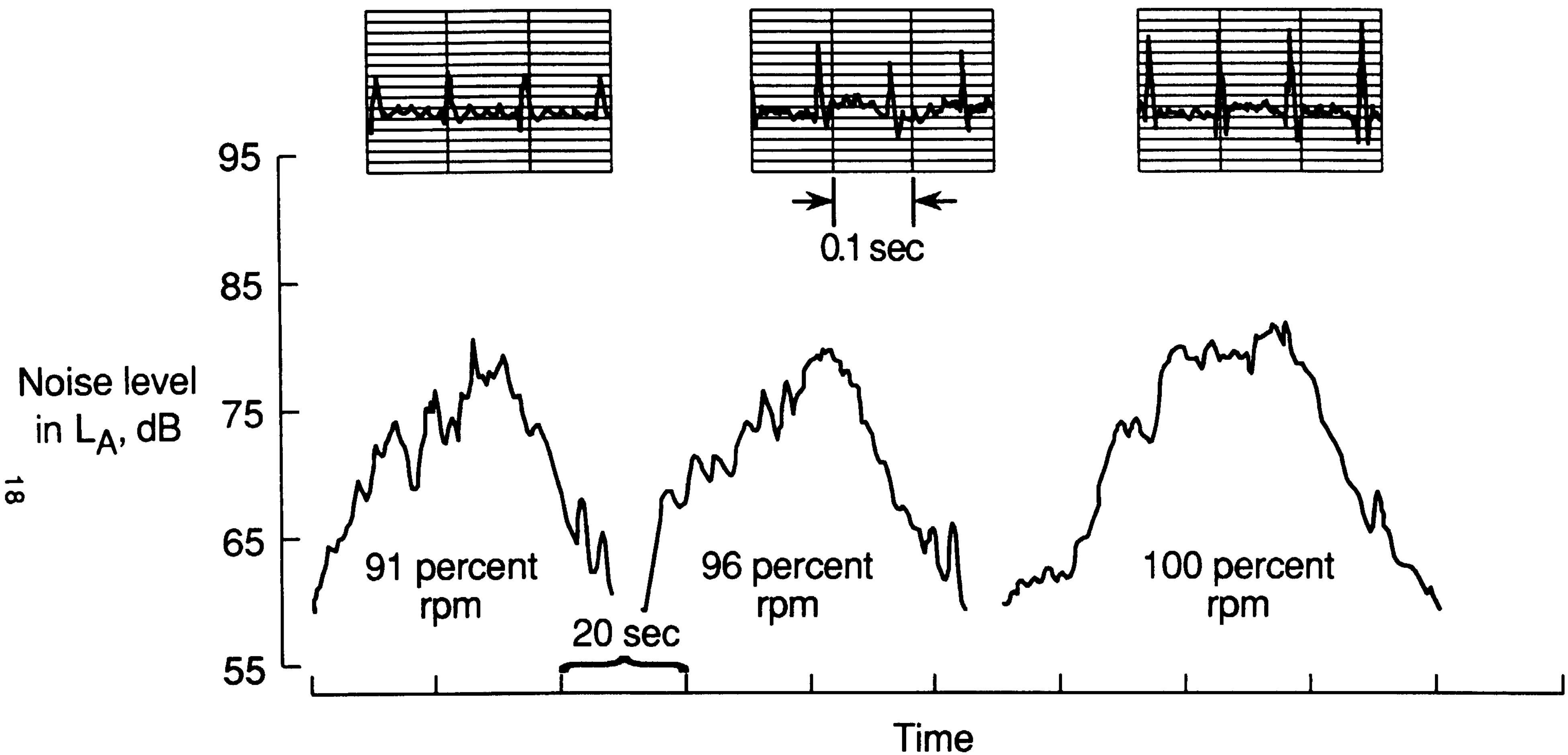
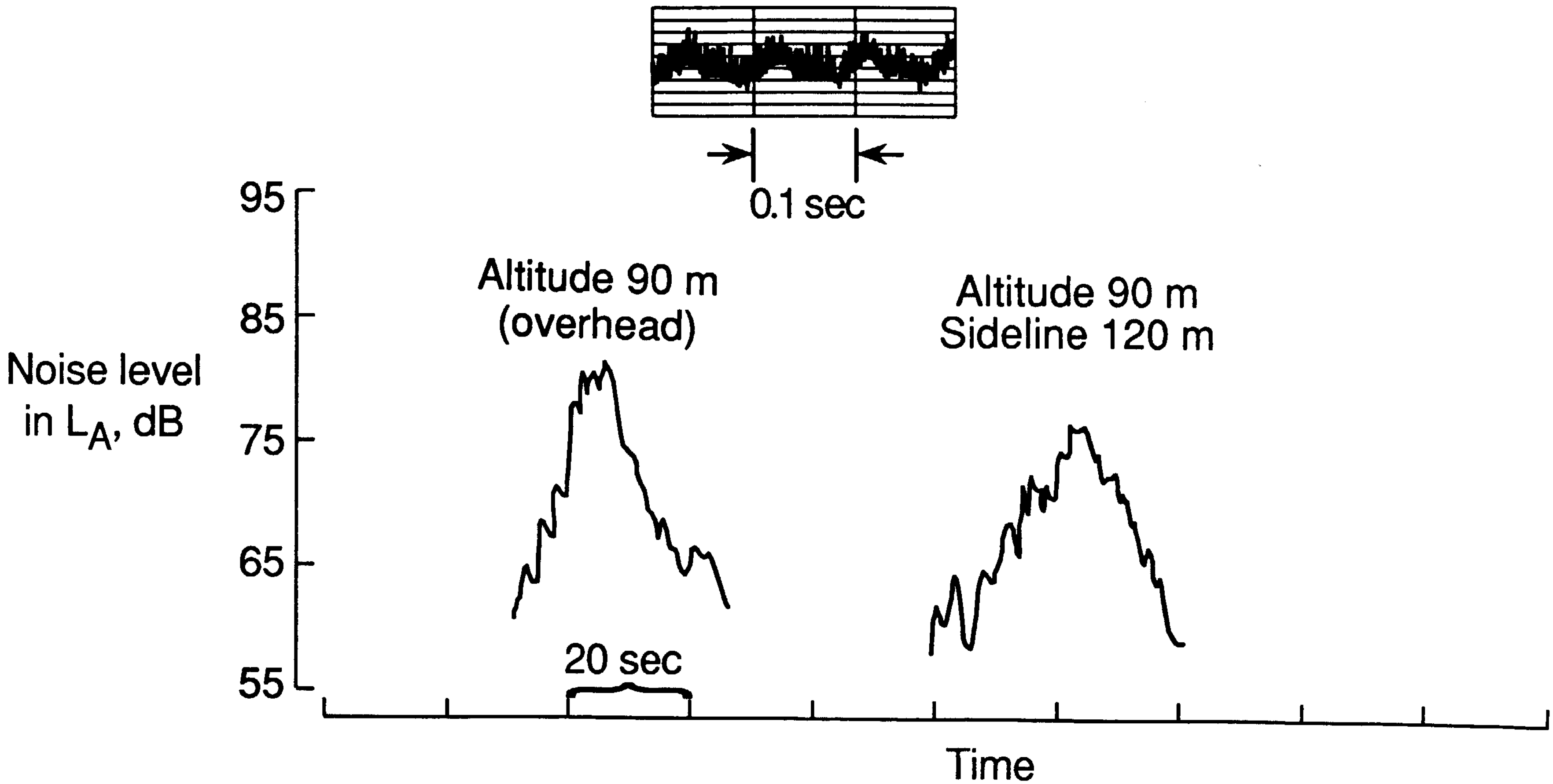


Figure 3. - Orientations of test houses and instrumentation relative t) aircraft flight paths.



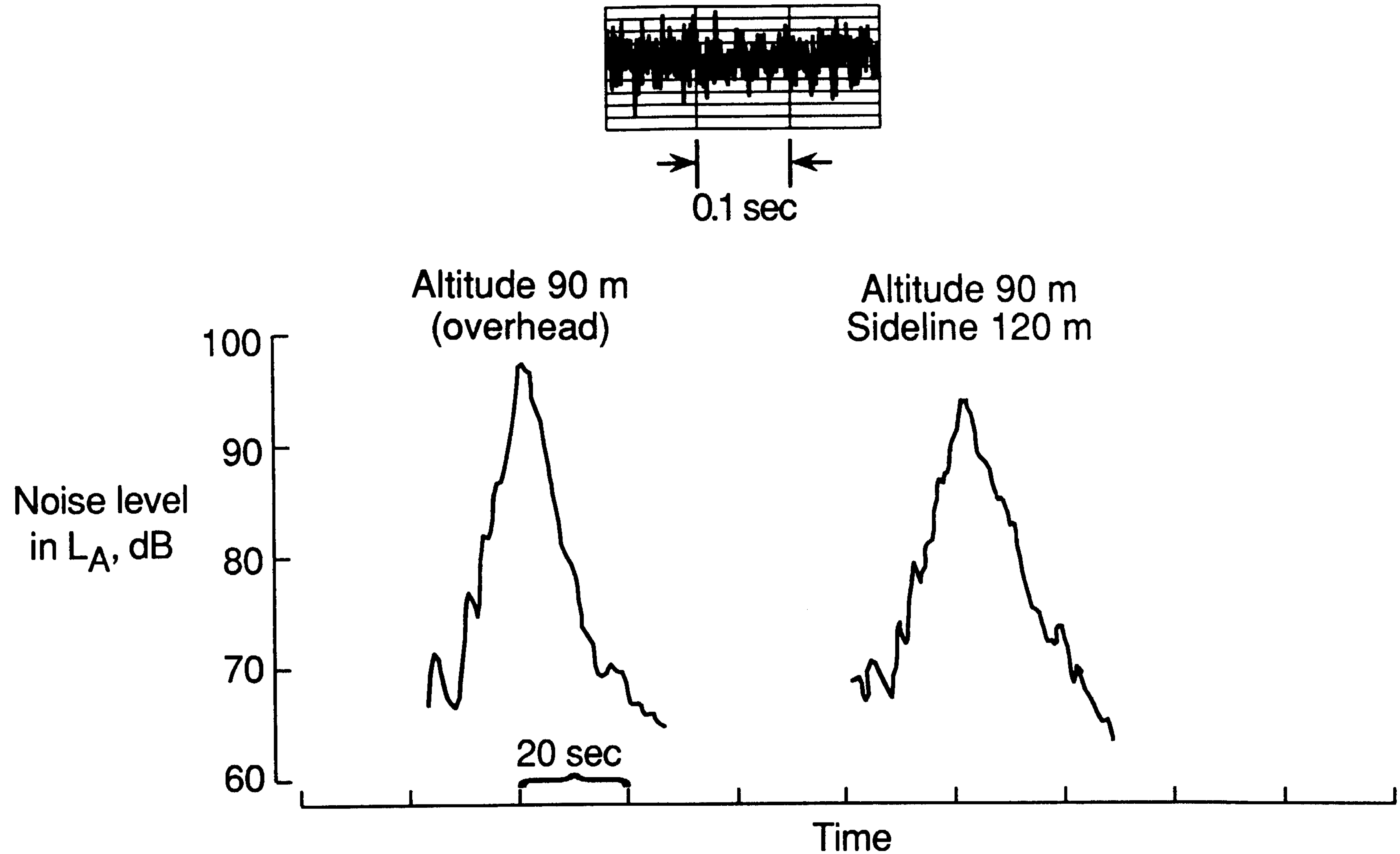
(a) Bell 204B, 90m altitude and 120m sideline distance

Figure 4. - Noise inputs to structures



(b) Bell OH-58A

Figure 4 - (Cont.)



(c) North American T-28

Figure 4. - (Concl.)

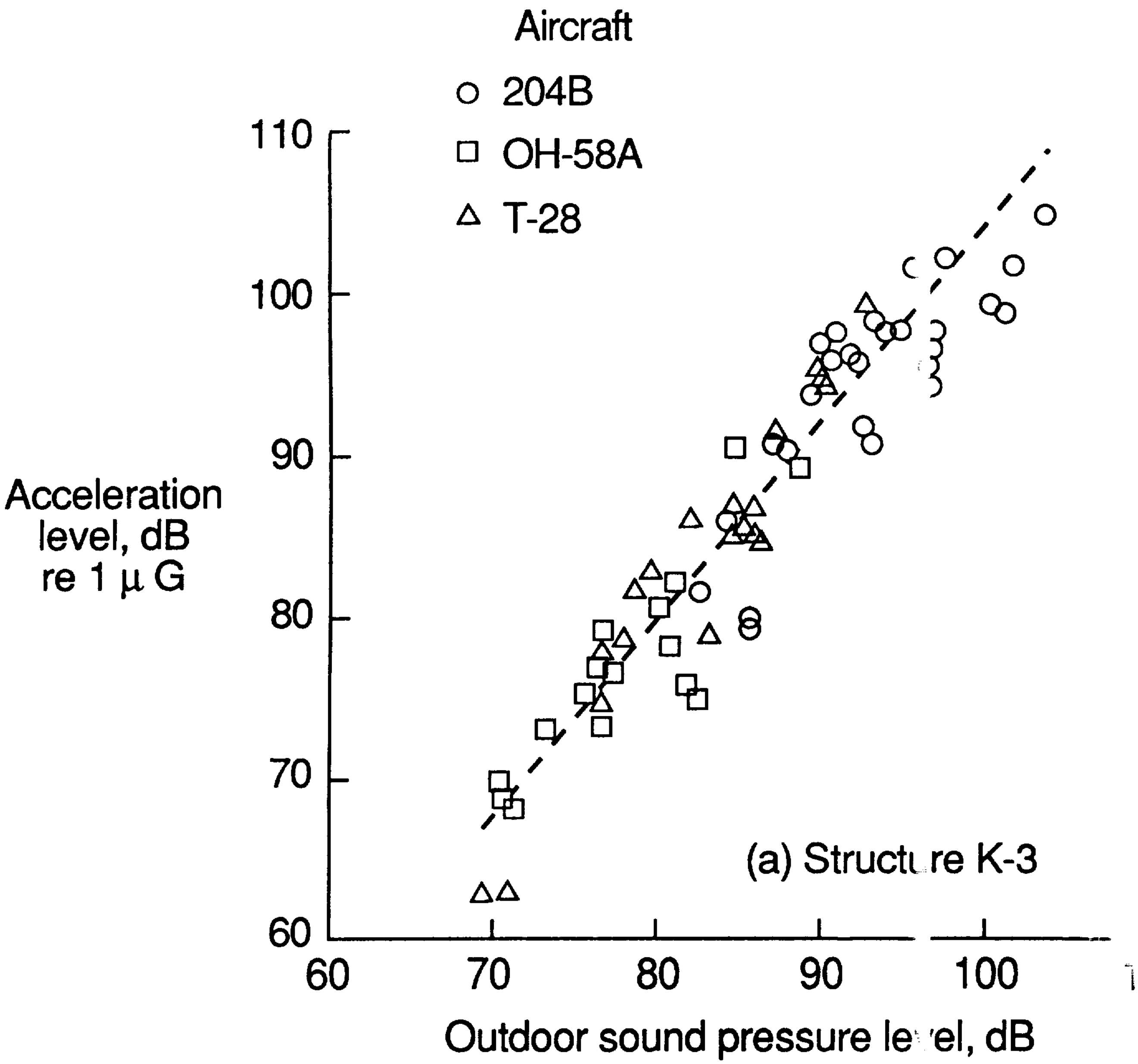


Figure 5. - Window acceleration measurements

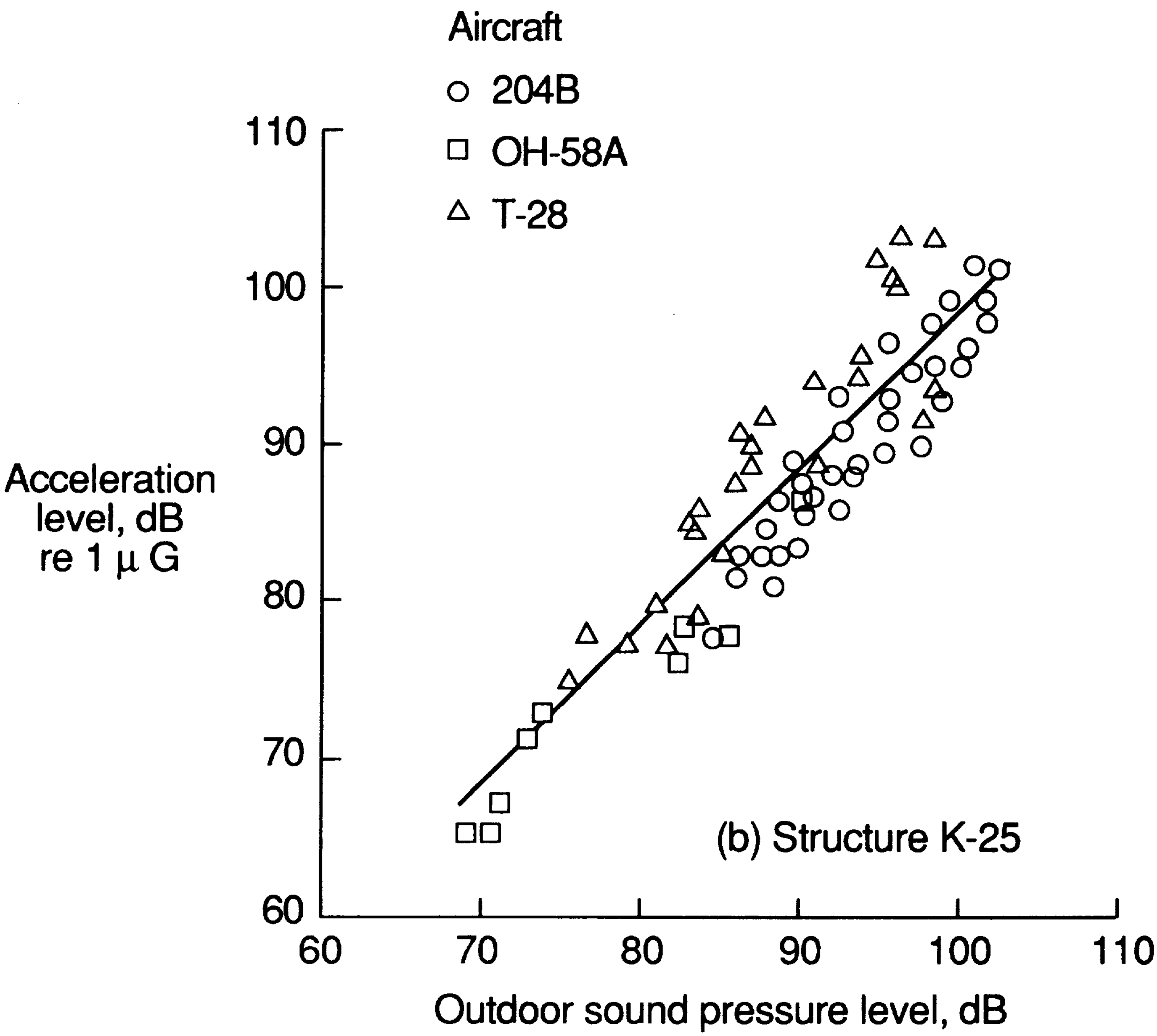


Figure 5. - (Concl.)

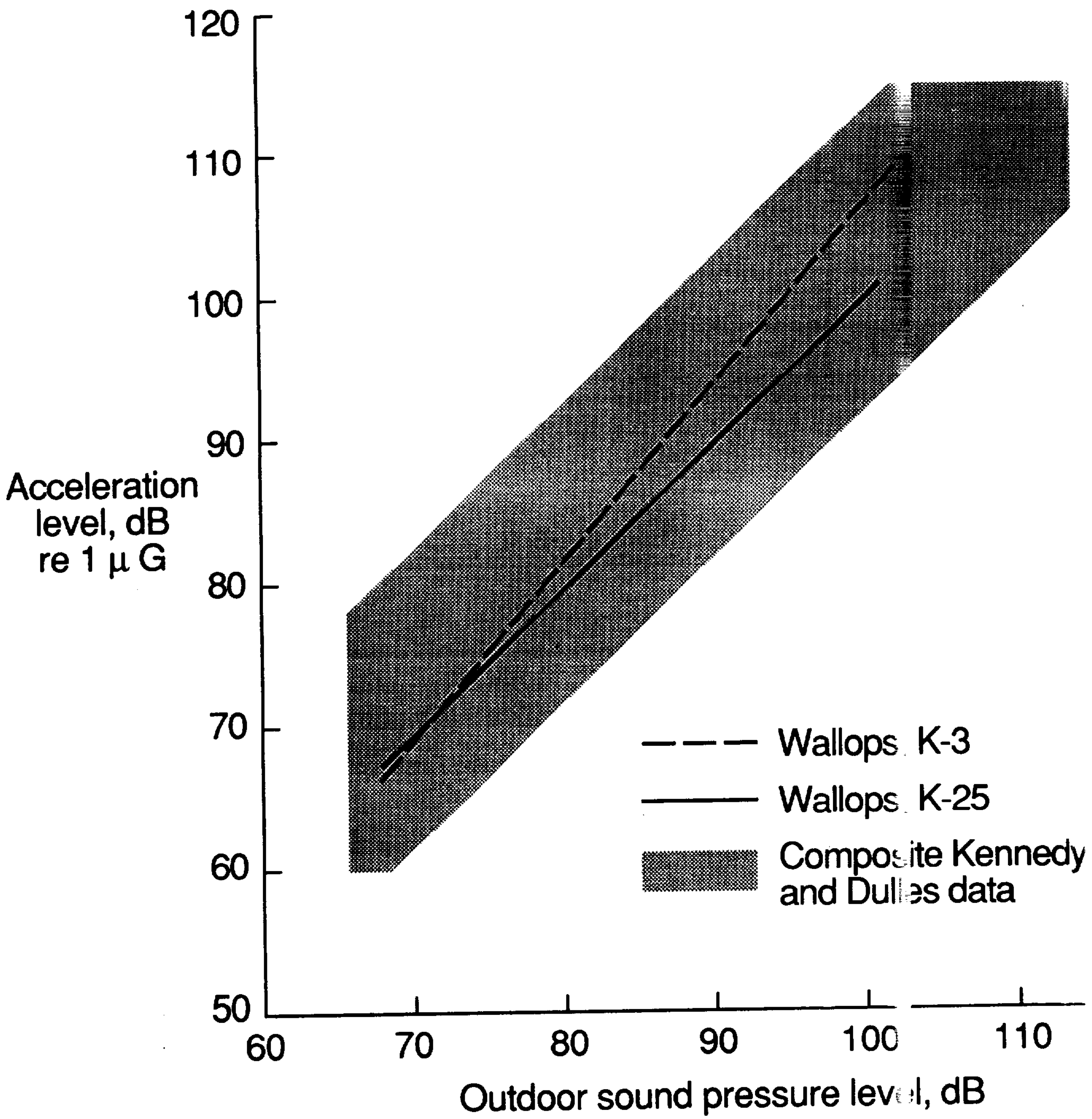


Figure 6. - Composite window responses

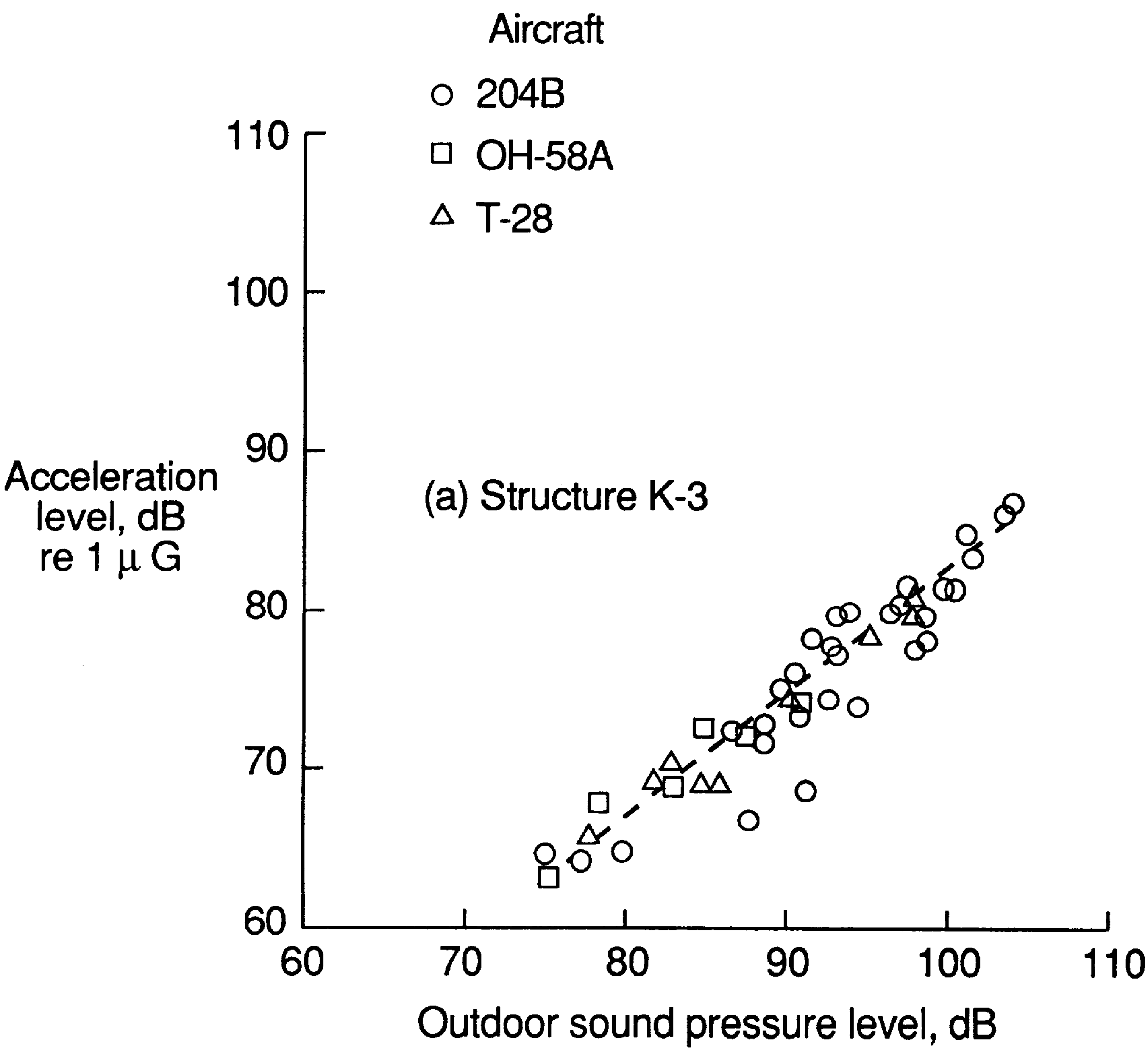


Figure 7. - Wall acceleration measurements

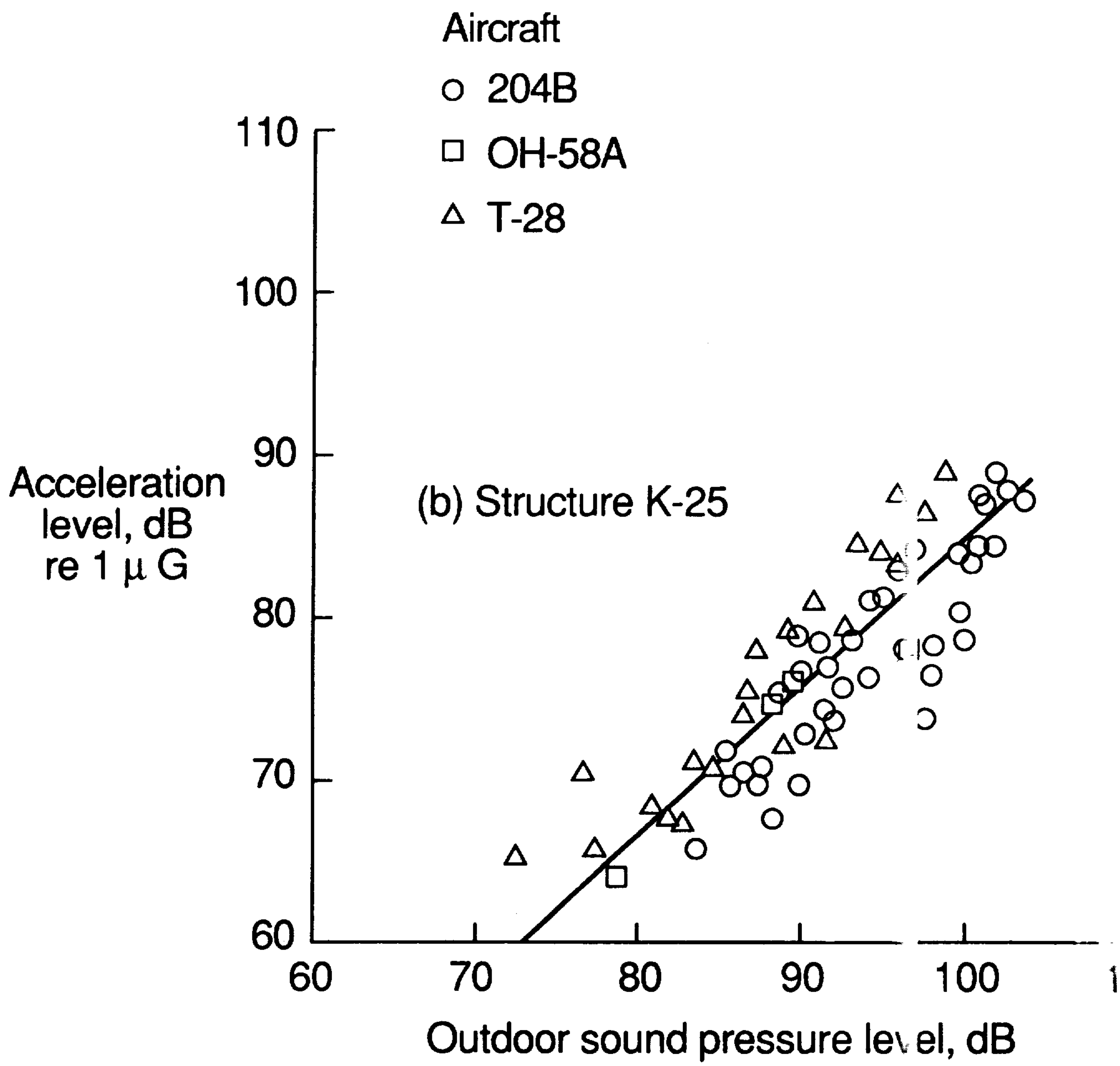


Figure 7. - (Concl.)

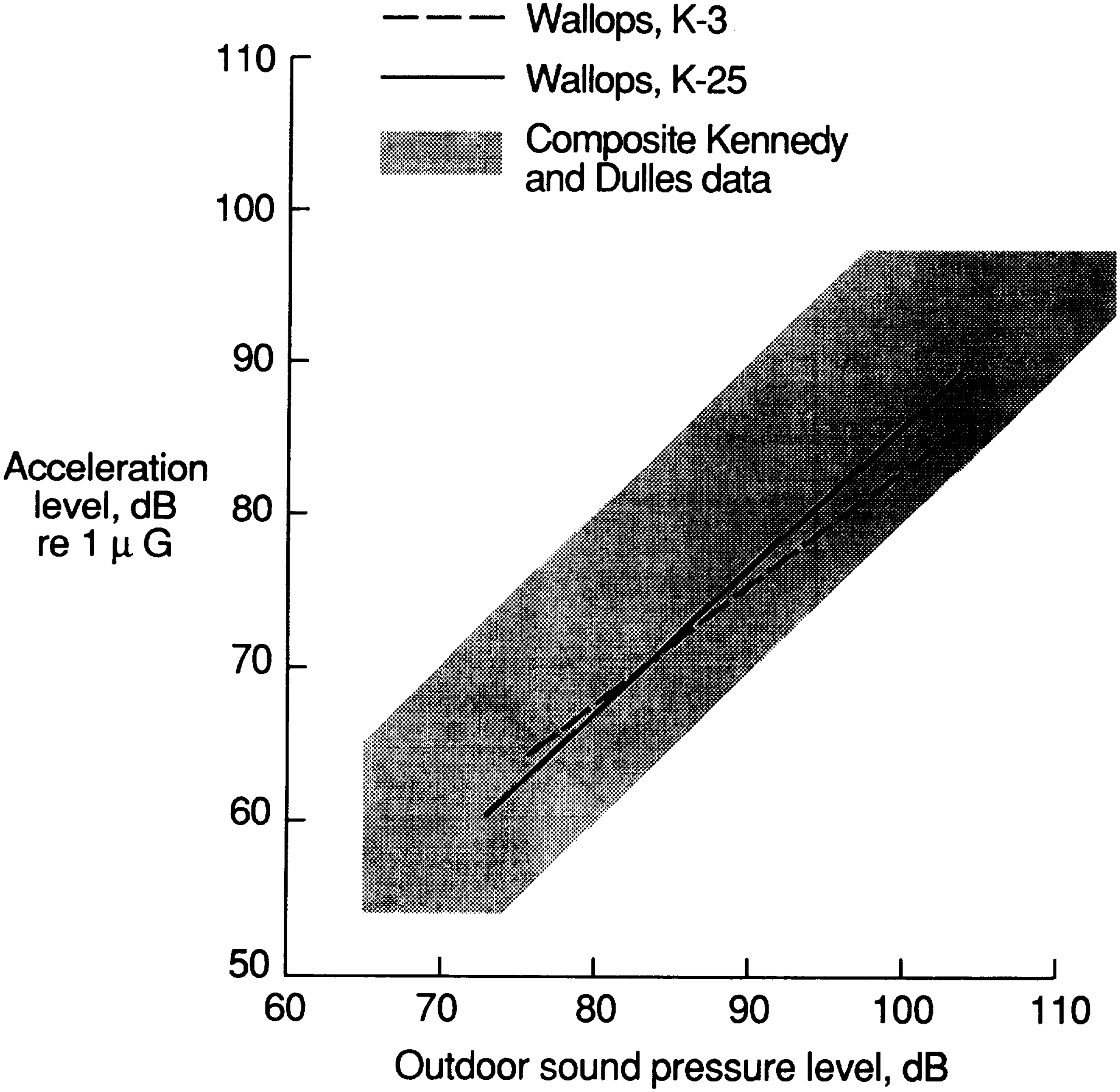
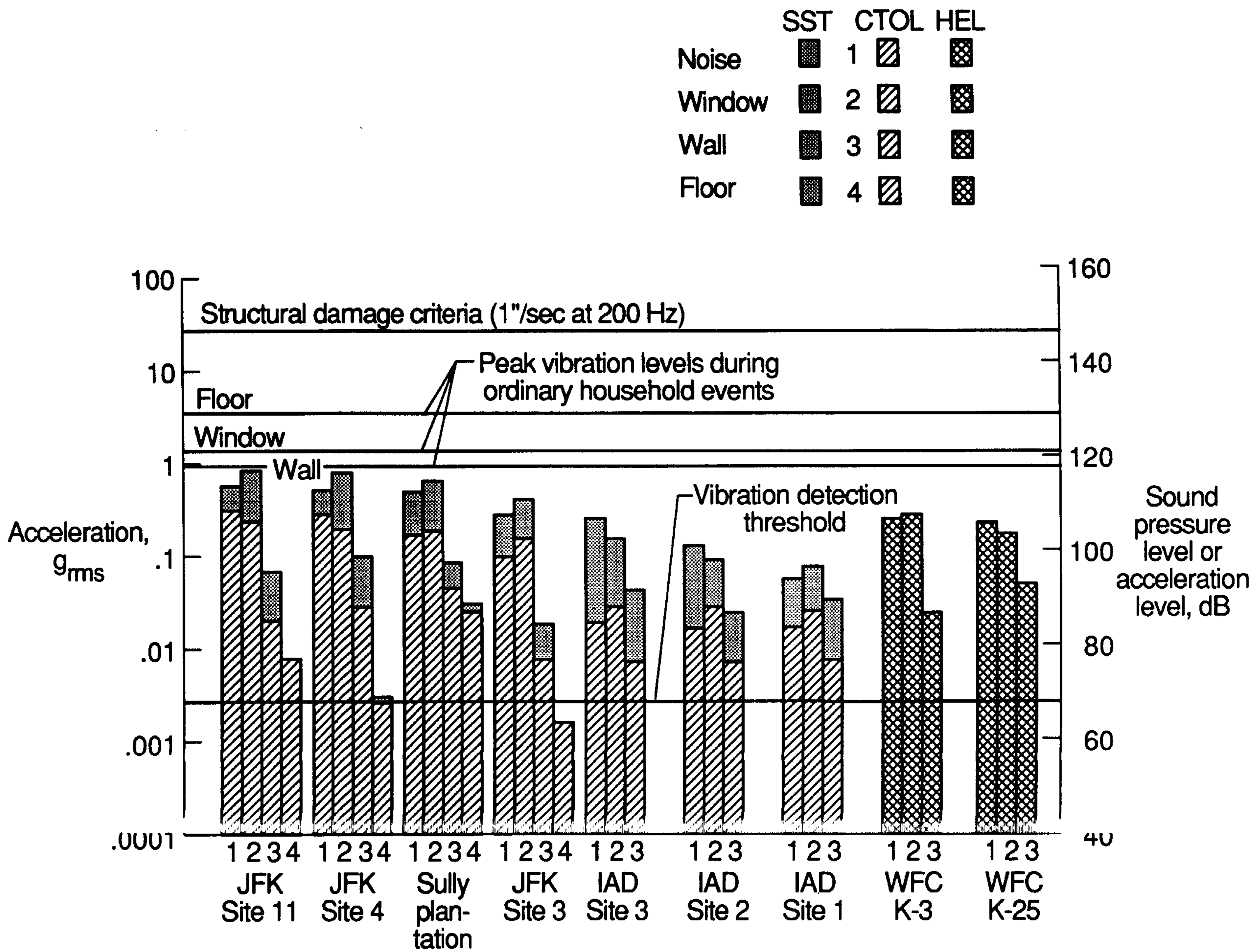


Figure 8. - Composite wall responses.


SST CTOL HEL
Noise 1
Window 2
Wall 3
Floor 4
Acceleration, g_{rms}
100
10
1
.1
.01
.001
.0001
Structural damage criteria (1"/sec at 200 Hz)
Peak vibration levels during ordinary household events
Floor
Window
Wall
Vibration detection threshold
160
140
120
100
80
60
40
Sound pressure level or acceleration level, dB
1 2 3 4
JFK Site 11
1 2 3 4
JFK Site 4
1 2 3 4
Sully plan-tation
1 2 3 4
JFK Site 3
1 2 3
IAD Site 3
1 2 3
IAD Site 2
1 2 3
IAD Site 1
1 2 3
WFC K-3
1 2 3
WFC K-25

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY *(Leave blank)*

2. REPORT DATE
June 1992

3. REPORT TYPE AND DATES COVERED
Technical Memorandum

4. TITLE AND SUBTITLE
Building Vibrations Induced by Noise From Rotorcraft and Propeller Aircraft Flyovers

5. FUNDING NUMBERS
535-03-11-03

6. AUTHOR(S)
Kevin P. Shepherd
Harvey H. Hubbard

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
NASA Langley Research Center
Hampton, VA 23665

8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
National Aeronautics and Space Administration
Washington, DC 20546

10. SPONSORING/MONITORING AGENCY REPORT NUMBER
NASA TM-104170

11. SUPPLEMENTARY NOTES
Kevin P. Shepherd: Langley Research Center, Hampton, Virginia.
Harvey H. Hubbard: Lockheed Engineering & Sciences Company, Hampton, Virginia.

12a. DISTRIBUTION/AVAILABILITY STATEMENT
Unclassified—Unlimited
Subject Category—71

12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*

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14. SUBJECT TERMS
House Structures; Acceleration Responses; Aircraft Noise

15. NUMBER OF PAGES
28

16. PRICE CODE
A03

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
Unclassified	Unclassified	Unclassified	

NSN 7540-01-280-5500

Standard Form 298 (Rev. 2-89)
Prescribed by ANSI Std Z39-18
298-102