N76-16768

HUMAN COMFORT IN RELATION TO SINUSOIDAL VIBRATION

B. Jones and B. K. N. Rao

Department of Mechanical Engineering
University of Birmingham

SUMMARY

An investigation has been made to assess the overall subjective comfort levels to sinusoidal excitations over the range 1 to 19 Hz using a two axis electrohydraulic vibration simulator. Exposure durations of 16 minutes, 25 minutes, 1 hour, and 2.5 hours have been considered. Subjects were not exposed over such durations, but were instructed to estimate the overall comfort levels preferred had they been constantly subjected to vibration over such durations.

14

INTRODUCTION

Meister and Reiher in 1931 (ref. 1) were some of the first research workers to examine the problem of human comfort in relation to sinusoidal vibration. Since then a wealth of information has been presented by various organisations. Recently, an ISO committee has attempted to define criteria, prescribe limits of exposure, and suggest methods of measurement with respect to comfort, performance, and safety, over the range 1 to 80 Hz. The resulting international standard "Guide for the Evaluation of Human Exposure to Whole-Body Vibration" identifies three main criteria of human reaction to vibration and defines the limits accordingly. These are:

(1) The preservation of working efficiencies, with the limiting fatigue-decreased proficiency (FDP) boundary

(2) The preservation of health or safety, with the 'exposure limit' boundary

(3) The preservation of comfort, with the limiting 'reduced comfort' boundary

The values for the reduced comfort boundary are based upon various studies relating to the transportation field, and the relationship between exposure time and frequency is shown in figures 1 and 2. The proposed comfort limits are related to a three-degree-of-freedom orthogonal coordinate system centred in the heart, and illustrated in figure 3. The decline in human tolerance presumed to occur with increasing exposure duration is clearly reflected in figures 1 and 2. It must be emphasised, however, that the proposals are

Preceding page blank

tentative since exposure duration as a factor affecting comfort has received very little study and firm data suitable as the basis for standardisation are limited.

The reported investigation relates to the following objectives:

(1) To estimate the overall subjective comfort levels (in weighted rms g)

(2) To evaluate the shape of the comfort contours (using ISO's weighting networks)

(3) To determine and compare the percentage deviations in rms g levels between the estimated comfort contours and the corresponding ISO proposals at various frequencies and exposure durations

TWO AXIS ELECTROHYDRAULIC VIBRATION SIMULATOR

The simulator used for the investigation is that of the RAE, Farnborough, and utilises a flat platform (183 x 122 cm), weighting around 200 kg and supported by three trunnion mounted hydraulic actuators. Two actuators support the table in the vertical axis and the third is attached horizontally to the table in the same plane. Each vertical actuator has a piston area of 11.3 cm with a stroke of ±25.4 cm and is controlled by three electrohydraulic servo valves. The horizontal actuator has a piston area 22.6 cm with a stroke of ±25.4 cm and is controlled by six servo valves.

Closed loop control of each actuator utilises position and piston differential pressure feed-back. Each servo valve has a maximum flow capability of 655.6 cm^3/s, giving a linear velocity limit of 152.4 cm/s in either axis.

The simulator performance permits a maximum acceleration of ±2 g and a frequency range of 0.5 to 50 Hz, on either or both of the axes, with a payload of 273 kg. Considerable off-centre loads are permitted.

Built-in oscillators provide the necessary displacement input and the frequency of the signals applied to the two axes can either be the same, with adjustable phase angle, or independently variable over the range 0.5 to 50 Hz. Facility is provided for input of external displacement or acceleration signals.

A piston differential pressure feed-back signal is used to reduce 'stiction' effects at the extremes of actuator motion and results in improved acceleration waveforms. Displacement feed-back is based upon a combination of the output from resolvers fitted to the bearing trunnions and a displacement transducer signal. This results in displacement feed-back proportional to true horizontal or vertical motion.

The performance of the simulator conforms to the following specification (ref. 2):

(a) Frequency response of 0 to -1.0 dB over the range 0.5 to 50 Hz.

(b) Phase lag not exceeding 20° at 5 Hz.

(c) Distortion of the fundamental acceleration sine wave less than 15%, over the range 1 to 10 Hz, measured at the platforms when fully loaded.

(d) The response of the system is stable over a 3-hour period when operating at maximum endurance.

(e) The platform is constructed so that the vertical forces applied at its centre can be reproduced at the extremities. The resonant frequency when unloaded is not less than 500 Hz.

(f) A safety feature allows the operator or the test subject to shut down the system with a maximum retardation of 10 g in the event of an emergency. Means are also provided to absorb and contain the kinetic and potential energy at the extremes of motion in the event of a control system malfunction.

SUBJECTS AND POSTURE

A total of seven subjects participated in the investigation and all relevant details are given in table 1. All subjects were considered to be normal and wore normal clothing and footwear. Before being subjected to the test programme all participants were requested to sign a declaration form in accordance with the draft guide on the safety aspects relating to human vibration experiments (ref. 3).

The experimental facilities and associated safety features were explained to each subject and the general purpose of the investigation indicated. Each subject was given detailed instructions (appendix A) of his/her specific role in the experiment.

Once the test programme was fully understood the subject was seated on a hard wooden seat mounted on the vibrator platform. A birdseed cushion pad was provided that gives a 1:1 transmission ratio up to 30 Hz. The dynamic response characteristics of this and other cushion materials are given in figure 4. A standard lap seat belt was used by all subjects, adjusted to a loose position in order to minimise restraining effects and still provide adequate safety precautions. Plate 1 illustrates the posture adopted throughout the investigation and figure 3 illustrates the orthogonal coordinate system adopted.

INSTRUMENTATION

It is clear from the ISO standard (ref. 4) that human whole-body response to vibration is frequency dependent (figures 1 and 2). The standard recognise the use of instrumentation for measurement of ride or vibration severity, using frequency weighting networks conforming to the standardised human frequency response embodied in the limits and specifies the precision required

Two frequency weighting networks corresponding to human response to vibra tion in the a_x (or a_y) and a_z axes were employed to measure comfort levels (figure 5). It will be observed that the ISO standard does not indicate limits for vibration frequencies below 1 Hz owing to the scarcity of data and lack of agreement in this region. However, the 0.1 to 1 Hz region is of some significance for evaluation of suspension performance and human postural sway in the a_x and a_y axes. Hence it becomes necessary to tentatively extrapolate the ISO characteristics. A single weighting function so designed can be made to apply to any amplitude and duration, since the boundaries recommended for various exposure durations, for a specific axis, follow the same amplitude-frequency relationship. The filter output coupled to a true rms digital voltmeter yields the normalised rms value of the input acceleration signal.

The set-up adopted consisted of measuring the acceleration level on the seat and very close to the subject's buttocks. The acceleration signal generated by a piezo-resistive accelerometer was processed through a carrier amplifier, weighting filter, and rms digital voltmeter.

GENERAL TEST PROCEDURE

Two people were required to operate the simulator. One operator, stationed at the control panel, monitored safety levels and controlled frequency and level of vibration. The investigator acted as general test supervisor and as such directed the test programme and monitored the required data. An intercom system provided the necessary communication links between the subject, investigator, and simulator operator during the test sessions.

Any relevant information volunteered by the subjects during the experimen was recorded and subjects were asked to comment on the nature of the experimen at the end of each session. Subjects were free to discuss the experiment throughout the investigation.

A general ambient noise level of 62 dB(A) was recorded at head level with the simulator operating, with earphones producing some attenuation. Room temperature varied from 20.6 to 21.7°C (69 to 71°F) with a relative humidity of 55 to 60%. Since the vibrator was enclosed within a walk-in chamber, a nondistracting environment was available for the test programme.

TEST PROGRAMME

Each subject was exposed to eight sinusoidal vibrations per axis, selected within the range from 1 to 20 Hz. Exposure durations of 16 minutes, 25 minutes, 1 hour, and 2.5 hours were considered. The order of stimulus presentation was randomised for each subject. Each experimental session per subject per axis consisting of eight frequencies and four exposure durations lasted just over 40 minutes. Each subject completed two sessions covering two axes on the same day, with at least a 30-minute interval between sessions. The remaining axis was covered after a lapse of at least 24 hours.

RESULTS

Vertical Mode Response (a_z Axis)

The estimated mean rms g comfort levels and the standard deviation for male and female subjects are presented in table 2. The shape of the comfort contours and the estimated overall mean rms g levels are indicated in figure 6.

It is significant that the contours bear little resemblance to the ISO 'reduced comfort boundary' contours, particularly in the low and high frequency regions. All contours indicate a maximum sensitivity at 1 Hz, decreasing to a minimum in the region 2 to 3 Hz, increasing to a maximum in the region 5 to 7 Hz, falling away in the region 8 to 15 Hz, and finally increasing at higher frequencies.

The trend observed below 2 Hz correlates well with the observations of Dupuis (ref. 5), Dupuis, Hartung and Louda (ref. 6), Ashley (ref. 7), and Ashley and Rao (ref. 8), although the techniques and objectives differed from those currently employed. The increase in sensitivity in the high frequency region has also been reported by Ashley (ref. 7), Ashley and Rao (ref. 8), Jones and Saunders (ref. 9), Miwa (ref. 10), Shoenberger and Harris (ref. 11), and Oborne and Clarke (ref. 12).

It is also noted that the estimated overall comfort levels appear to be significantly higher than the corresponding ISO 'reduced comfort boundary' standards. Examination of table 2 and figure 6 indicates that human beings in a seated position can comfortably tolerate relatively high g levels in the frequency range 2 to 3 Hz, thus suggesting that seats and suspension systems should be based around a natural frequency of this order. It should be noted that Rao and Jones (ref. 13) and Simic (ref. 14) have observed that this frequency corresponds to the natural frequency of normal walking and that as a result humans possess a high tolerance to rms g levels at this frequency.

The data also indicate that, in general, the male can comfortably withstand higher rms g levels than the female. This tentative conclusion is based upon a small number of subjects and must be viewed with caution.

The increase in sensitivity at high frequencies compared to the ISO standards suggests that from the point of view of comfort, human beings do not prefer high frequency to the body. This aspect was emphasised during the test programme by comments made by subjects that at frequencies greater than 10 Hz, cramp sensations were experienced in the feet and thighs, fluttering sensation in the face and lower back, and speech modulation and blurred vision at around 20 Hz.

Finally, the relationship between estimated rms g level and estimated exposure time appears to be much less exaggerated than expected. (See tables 3(a) and 3(b).) It should be noted that this observation is based upon the mean values. Furthermore, subjects were required to extrapolate their comfort judgement of a short term vibration experience to a long term exposure, which proved extremely difficult for durations exceeding 25 minutes.

Side-to-Side Vibrational Mode (a_y Axis)

The test results are presented in table 4 and figure 7 shows the estimated overall mean rms g levels against frequency for both male and female subjects.

Sensitivity approaches a minimum towards 1 Hz and above 11 Hz tends to increase. It is interesting to note below 10 Hz the contours tend to follow the threshold of perception contours of Meister (ref. 15), Von Bekesy (ref. 16), Kanazawa (ref. 17), citing Ishimoto and Ootsuka, and Loach (ref. 18). In relation to the ISO the contours exhibit a higher comfort threshold below 7 Hz and a lower threshold above 7 Hz.

A number of contributory features reported by test subjects relate to the increased sensation above 7 Hz:

(a) 'Pins and needles' sensation in legs (11 to 13 Hz)

(b) Increased vibratory sensations in stomach, legs, and feet (8 to 9 Hz), causing difficulty in keeping the feet still

(c) 'Pins and needles' sensations in the calf muscles, thighs and buttocks (15 to 20 Hz)

Test subjects reported that at frequencies below 7 Hz, the head, shoulders, hips, knees, and feet were out of phase with each other.

Front-to-Rear Vibrational Mode (a_x Axis)

The test results are presented in table 5 and figure 8 shows the estimated overall comfort levels. In general terms the contours are of a similar form to those for the a_y axis and agree with the threshold of perception characteristics reported by Meister (ref. 15), Von Bekesy (ref. 16), and Kanazawa (ref. 17), citing Ishimoto and Ootsuka.

Below 9 Hz the comfort levels are higher than expected and above 9 Hz the levels are below those of the ISO 'reduced comfort boundary' values. These findings are in good agreement with those relating to the a_y axis. It is interesting to note that females exhibit a higher tolerance to acceleration level than do males.

A comparison of the estimated overall comfort levels between a_x and a_y axes indicates that subjects, in general, can tolerate higher acceleration levels in the a_x axis; a fact which is at variance with the ISO standards.

As expected large standard deviation values have been obtained due to the small sample size and the extrapolation involved.

The percentage deviation in comfort levels between the 16-minute and 2.5-hour exposure durations have been compared with the related ISO comfort levels and the results given in table 6.

CONCLUSIONS

The current investigation was mainly concerned with the object of estimating the overall subjective comfort levels (in weighted rms g) in response to sinusoidal vibrations applied separately to the a_x, a_y, a_z axes. The estimated comfort levels were extrapolated to 16 minutes, 25 minutes, 1 hour, and 2.5 hours. The results have indicated the following broad conclusions:

(1) A significant variation in the form of the contours for all three axes has been observed in comparison with the ISO standards.

(2) Generally, a much higher comfort level is exhibited for the vertical vibration mode (a_z axis). Regarding the a_x and a_y axes the comfort levels are higher in the range 1 to 9 Hz and lower in the range 9 to 20 Hz.

(3) The relationships between comfort levels and exposure duration relating to the a_x and a_y axes differ from the corresponding ISO contours.

While accepting that the sample size is small and the study is nonexhaustive, the a_z axis results support available evidence that the ISO standard requires some modification below 2 Hz. One such modification has recently been proposed by Allen (ref. 19) and is shown in figure 9. In addition the present study suggests that there is need for modification of the contours above 8 Hz.

The a_x and a_y axes data also suggest that the ISO standard requires some modification. Figure 10 indicates a contour profile more in line with the results of the present investigation.

ACKNOWLEDGEMENTS

The authors are grateful for the financial support of the Science Research Council and to the University of Birmingham for providing the facilities.

The authors wish to express their gratitude to the Chief and Staff of Human Engineering Division of the Royal Aircraft Establishment, Farnborough, for providing their multi-axis simulator facilities, and to all those subjects who kindly volunteered to participate in this investigation.

APPENDIX A

SUBJECTS' INSTRUCTIONS

The object of this investigation is to assess the overall subjective comfort levels to various sinusoidal vibrations.

Sit straight but relaxed on the cushioned seat mounted on the vibrator platform with your palms on the knees and your feet flat on the vibrator platform. Sit as still and erect as possible without swaying or moving your body unnecessarily. Do not lean against the backrest. Wear the seat belt loosely. Put on the headset for voice communication with experimentor and vibrator operator. A "panic button" switch is conveniently positioned near your right hand. If during the investigation you feel not too happy about the vibration condition due to any reason, you may at any time, stop the functioning of the vibrator by pressing the "panic button."

In this experiment you will be subjected to a certain sinusoidal vibration. Imagine that if you are continuously exposed to this vibration for a prescribed duration of time (say, 16 minutes, 25 minutes, 1 hour or 2.5 hours) what acceleration level would you prefer to be exposed for an overall comfortable ride?

For the purposes of this experiment, the term 'overall comfort level' is defined as the level that you can comfortably tolerate over the prescribed duration while doing the routine tasks (such as reading, writing, sleeping, eating, etc.) during travelling. Give clear instructions to the vibrator operator through the intercom system to adjust the acceleration level you prefer to be comfortably exposed. You may take your own time to reach your decision. After you have positively decided about the preferred comfort level, let the Experimentor know of your decision, so that he can take a few readings before proceeding further. The above procedure will be repeated many times for different frequencies and in different axis of reference.

This investigation is solely dependent on your skill and keenness of your judgement. Please maintain constant alertness throughout the experiment.

If you have any questions please ask them now.

Thanks for your cooperation.

REFERENCES

1. Reiher, H.; and Meister, F. J.: Die Empfindichkeit des menschen gegen Erschutterungen. Foschung auf dem gebiete des Ingenieurswesens, vol. 2, 1931, pp. 381-386.

2. Rowlands, G. F.: Performance of New Two-Axis Vibrator. Human Response to Vibration Conference Held at University of Sheffield, 1972.

3. British Standards Institution: Draft for Development: Guide to the Safety Aspects of Human Vibration Experiments. B.S.I. DD23:, 1973.

4. International Organisation for Standardisation: Guide for the Evaluation of Human Exposure to Whole-Body Vibration. International Standard ISO 2631-1974(E), 1974.

5. Dupuis, H.: The Physiological Strain Caused to the Human Body by Mechanical Oscillations. (In German.) Fortschr Berichte VDI-Z Series II, no. 7, 1969.

6. Dupuis, H.; Hartung, E.; and Louda, L.: The Effect of Random Vibrations of a Limited Frequency Band Compared with Sinusoidal Vibrations on Human Beings. (In German.) RAE Library Translation No: 1663, December 1971.

7. Ashley, C.: Equal Annoyance Contours for the Effect of Sinusoidal Vibration on Man. The Shock and Vibration Bulletin, Bull. 41, pt. 2, 1970, pp. 13-20.

8. Ashley, C.; and Rao, B. K. N.: An Equal Sensation Study of Differential Vibration between Feet and Seat. Ergonomics, vol. 17, no. 3, 1974, pp. 331-342.

9. Jones, A. J.; and Saunders, D. J.: Equal Comfort Contours for Whole Body Vertical, Pulsed Sinusoidal Vibration. Journal of Sound and Vibration, vol. 23, no. 1, 1972, pp. 1-14.

10. Miwa, T.: Evaluation Methods for Vibration Effect, Part 1. Industrial Health (Japan), vol. 5, 1967, pp. 182-205.

11. Shoenberger, R. W.; and Harris, C. S.: Psychophysical Assessment of Whole Body Vibration. Report No. AMRL-TR-69-87, Wright Patterson Air Force Base, 1969.

12. Oborne, D. J.; and Clarke, M. J.: The Determination of Equal Comfort Zones for Whole-Body Vibration. Ergonomics, vol. 17, no. 6, 1974, pp. 769-782.

13. Rao, B. K. N.; and Jones, B.: Some Studies on Human Response to Walking and Riding in Vehicles. Human Response to Vibration Conference Held at Westland Helicopters, Ltd., Yeovil, 1974.

14. Simic, D.: Contribution to the Optimisation of the Oscillatory Properties of a Vehicle: Physiological Foundations of Comfort during Oscillations. Doctoral Dissertation D.83, Technical University of Berlin, 1970. RAE Library Translation No: 1707, February 1974.

15. Meister, F. J.: Die Empfindlichkeit des Menschen gegen Erschütter-ungen. Foschung auf dem Gebiet des Ing-wesens, vol. 6, 1935, pp. 116-120.

16. Von Bekesy, G.: The Sensitivity of Standing and Sitting Man to Sinusoidal Vibration (in German). Akustische Zeit, vol. 4, 1939, pp. 360-369.

17. Kanazawa, T.: A Proposal for the Vibration Limits of Ships. Schiff und Hafen, vol. H 7, 1961, pp. 602-606.

18. Loach, J. C.: A New Method of Assessing the Riding of Vehicles. Journal of the Institute of Locomotive Engineers, vol. 48, 1958, p. 183.

19. Allen, G. R.: Initial Proposals to I.S.O. for Vibration Exposure below 1 Hz, with Some Modification to DIS 2631 below 2 Hz. Human Response to Vibration Conference Held at University of Salford, 1973.

TABLE 1

Subject Details and Statistical Analysis

Subject Identification Male- M Female-F	Age (years)	Height (cm)	Weight (Kg)	Nationality	Statistical parameters	Subject	Age (years)	Height (cm^2)	Weight (Kg)
M. 1	21	175.3	73.2	British	Mean	Males	26.3	174.45	68.4
M. 2	28	173.7	70	British		Females	21.7	169.6	60.6
M. 3	24	170	66.8	British	Standard Deviation	Males	4.79	3.65	4.13
M. 4	32	178.8	63.6	British		Females	4.04	10.74	8.9
F. 1	26	181.2	70	British					
F. 2	21	167.6	59.5	British					
F. 3	18	160	52.3	British					

TABLE 2

Comfort Evaluation Studies of Males and Females.
Comparison of Mean RMS 'g' and SD Results.
a_z axis excitation.

Time	Freq. (Hz)	Reduced Comfort Boundary Levels from ISO (RMS 'g')	Mean RMS 'g' Values of			SD Values of		
			Males	Females	Males + Females	Males	Females	Males + Females
16 MIN	1	0.14	0.17	0.10	0.14	0.04	0.06	0.06
	3	0.076	0.21	0.17	0.19	0.08	0.16	0.10
	5	0.066	0.14	0.09	0.11	0.01	0.06	0.04
	6	0.066	0.13	0.10	0.11	0.05	0.06	0.05
	8	0.066	0.16	0.15	0.16	0.08	0.06	0.07
	10	0.082	0.16	0.20	0.17	0.08	0.17	0.10
	15	0.12	0.20	0.13	0.17	0.06	0.11	0.09
	19	0.155	0.16	0.08	0.13	0.05	0.05	0.06
25 MIN	1	0.115	0.10	0.07	0.09	0.06	0.02	0.05
	2	0.08	0.16	0.13	0.15	0.04	0.03	0.04
	4	0.056	0.13	0.11	0.12	0.02	0.04	0.03
	7	0.056	0.14	0.11	0.13	0.03	0.04	0.03
	9	0.062	0.16	0.13	0.15	0.04	0.01	0.03
	11	0.076	0.10	0.11	0.10	0.03	0.01	0.02
	13	0.09	0.13	0.07	0.11	0.07	0.01	0.06
	17	0.117	0.12	0.05	0.09	0.02	0.02	0.04

Continuation.....

Table 2. Comfort Evaluation Studies of Males and Females. Comparison of Mean RMS 'g' and SD Results.

Time	Freq (Hz)	Reduced Comfort Boundary Levels from ISO (RMS 'g')	Mean RMS 'g' values of			SD Values of		
			Males	Females	Males + Females	Males	Females	Males + Females
	1	0.076	0.12	0.06	0.10	0.05	0.01	0.05
	3	0.044	0.11	0.15	0.13	0.04	0.10	0.07
	5	0.037	0.10	0.10	0.10	0.02	0.07	0.04
1	6	0.037	0.07	0.09	0.08	0.05	0.05	0.05
HOUR	8	0.037	0.11	0.09	0.11	0.07	0.04	0.06
	10	0.047	0.10	0.12	0.11	0.06	0.01	0.05
	15	0.070	0.09	0.10	0.09	0.08	0.03	0.06
	19	0.088	0.08	0.07	0.08	0.04	0.02	0.03
	1	0.046	0.08	0.06	0.07	0.06	0.01	0.05
	2	0.032	0.11	0.14	0.12	0.04	0.05	0.05
	4	0.022	0.12	0.08	0.10	0.02	0.01	0.03
	7	0.022	0.06	0.05	0.05	0.05	0.03	0.04
	9	0.025	0.10	0.05	0.08	0.05	0.02	0.05
	11	0.031	0.10	0.08	0.09	0.08	0.04	0.06
2.5	13	0.037	0.11	0.05	0.08	0.10	0.02	0.08
HOURS	17	0.048	0.08	0.05	0.07	0.08	0.02	0.06

TABLE 3 (a)

a_z axis Excitation. Percentage Deviation in RMS 'g' Level Between 16-minute and 1-hour 'Reduced Comfort Boundary' Contours

Frequency, Hz	1	3	5	6	8	10	15	19
ISO 2631 (1974) (in %)	44	43	43	44	44	43	43	43
Current Findings (in %)	28	31	9	27	31	35	47	38

TABLE 3 (b)

a_z axis Excitation. Percentage Deviation in RMS 'g' Level Between 25-minute and 2.5-hour 'Reduced Comfort Boundary' Contours

Frequency, Hz	1	2	4	7	9	11	13	17
ISO 2631 (1974) (in %)	60	60	60	60	60	60	60	60
Current Findings (in %)	22	20	16	61	46	10	27	22

TABLE 4

Comfort Evaluation Studies of Males and Females.

Comparison of Mean RMS 'g' and SD Results

a_y axis excitation

Time	Freq (Hz)	Reduced Comfort Boundary Levels from ISO (RMS 'g')	Mean RMS 'g' values of			SD Values of		
			Males	Females	Males + Females	Males	Females	Males + Females
16 MIN	1	0.048	0.32	0.13	0.24	0.20	0.07	0.18
	3	0.071	0.28	0.12	0.21	0.14	0.11	0.15
	5	0.12	0.26	0.10	0.19	0.12	0.09	0.13
	7	0.164	0.27	0.08	0.19	0.20	0.08	0.18
	9	0.215	0.26	0.13	0.20	0.18	0.12	0.16
	11	0.26	0.30	0.09	0.21	0.24	0.10	0.21
	13	0.31	0.27	0.10	0.19	0.16	0.09	0.15
	17	0. 40	0.25	0.07	0.17	0.18	0.06	0.16
25 MIN	1	0.04	0.23	0.09	0.17	0.13	0.07	0.12
	3	0.06	0.15	0.09	0.12	0.09	0.09	0.08
	5	0.10	0.16	0.06	0.12	0.12	0.06	0.10
	7	0.14	0.18	0.06	0.13	0.15	0.03	0.12
	9	0.18	0.20	0.08	0.15	0.14	0.06	0.12
	11	0.22	0.17	0.06	0.13	0.11	0.05	0.10
	13	0.26	0.21	0.07	0.15	0.16	0.05	0.14
	17	0.34	0.15	0.04	0.10	0.14	0.03	0.11

Continuation .....

Table 4. Comfort Evaluation Studies of Males and Females. Comparison of Mean RMS 'g' and SD Results

Time	Freq. (Hz)	Reduced Comfort Boundary Levels from ISO (RMS 'g')	Mean RMS 'g' values of			SD Values of		
			Males	Females	Males + Females	Males	Females	Males + Females
	1	0.027	0.18	0.08	0.14	0.16	0.03	0.13
	3	0.04	0.14	0.08	0.11	0.11	0.07	0.09
	5	0.068	0.11	0.05	0.08	0.09	0.03	0.07
1	7	0.094	0.16	0.07	0.12	0.15	0.03	0.12
HOUR	9	0.12	0.15	0.06	0.11	0.13	0.04	0.11
	11	0.15	0.14	0.07	0.11	0.13	0.04	0.10
	13	0.17	0.16	0.06	0.12	0.14	0.04	0.11
	17	0.23	0.12	0.04	0.09	0.10	0.03	0.08
	1	0.016	0.11	0.10	0.11	0.08	0.05	0.06
	3	0.024	0.09	0.06	0.08	0.07	0.06	0.06
	5	0.04	0.09	0.05	0 07	0.08	0.04	0.06
2.5	7	0.057	0.12	0.06	0.09	0.13	0.04	0.10
	9	0.074	0.10	0.08	0.09	0.09	0.06	0.07
HOURS	11	0.09	0.09	0.07	0.08	0.10	0.05	0.08
	13	0.105	0.08	0.06	0.08	0.08	0.06	0.07
	17	0.14	0.07	0.04	0 .05	0.05	0.03	0.04

TABLE 5

Comfort Evaluation Studies of Males and Females.
Comparison of Mean RMS 'g' and SD Results.

a_x axis excitation

Time	Freq. (Hz)	Reduced Comfort Boundary Levels from ISO (RMS 'g')	Mean RMS 'g' Values of Males	Mean RMS 'g' Values of Females	Mean RMS 'g' Values of Males + Females	SD Values of Males	SD Values of Females	SD Values of Males + Females
16 MIN	1	0.048	0.21	0.42	0.30	0.09	0.18	0.16
	3	0.071	0.16	0.27	0.21	0.06	0.17	0.12
	5	0.12	0.14	0.24	0.18	0.09	0.10	0.10
	7	0.165	0.15	0.24	0.19	0.07	0.08	0.08
	9	0.215	0.19	0.38	0.27	0.09	0.29	0.20
	11	0.26	0.18	0.28	0.23	0.05	0.20	0.13
	13	0.31	0.14	0.30	0.21	0.04	0.24	0.16
	17	0.40	0.13	0.20	0.16	0.04	0.15	0.10
25 MIN	1	0.04	0.33	0.37	0.35	0.26	0.10	0.20
	3	0.06	0.24	0.24	0.24	0.19	0.18	0.17
	5	0.10	0.24	0.23	0.23	0.25	0.17	0.20
	7	0.14	0.24	0.22	0.23	0.19	0.07	0.14
	9	0.18	0.21	0.24	0.22	0.15	0.13	0.13
	11	0.22	0.21	0.18	0.20	0.10	0.10	0.09
	13	0.26	0.24	0.17	0.21	0.14	0.10	0.12
	17	0.34	0.21	0.11	0.17	0.18	0.05	0.14

Continuation ..... Table 5. Comfort Evaluation Studies of Males and Females. Comparison of Mean RMS 'g' and SD Results.

Time	Freq. (Hz)	Reduced Comfort Boundary Levels from ISO (RMS 'g')	Mean RMS 'g' Values of			SD Values of		
			Males	Females	Males + Females	Males	Females	Males + Females
1 HOUR	1	0.027	0.18	0.21	0.20	0.06	0.08	0.06
	3	0.04	0.16	0.20	0.18	0.12	0.05	0.09
	5	0.068	0.15	0.15	0.15	0.10	0.05	0.08
	7	0.094	0.10	0.11	0.11	0.03	0.02	0.03
	9	0.12	0.12	0.17	0.14	0.03	0.13	0.08
	11	0.15	0.14	0.16	0.15	0.06	0.07	0.06
	13	0.17	0.10	0.16	0.13	0.03	0.08	0.06
	17	0.23	0.08	0.12	0.10	0.02	0.04	0.03
2.5 HOURS	1	0.016	0.08	0.37	0.20	0.03	0.14	0.17
	3	0.024	0.04	0.22	0.10	0.01	0.08	0.10
	5	0.04	0.06	0.13	0.09	0.02	0.06	0.05
	7	0.057	0.07	0.14	0.10	0.01	0.07	0.05
	9	0.074	0.06	0.14	0.09	0.02	0.08	0.06
	11	0.09	0.05	0.13	0.08	0.005	0.05	0.04
	13	0.105	0.06	0.14	0.09	0.01	0.06	0.05
	17	0.14	0.06	0.09	0.07	0.008	0.03	0.02

TABLE 6

a_x axis Excitation. Percentage Deviation in RMS 'g' Level Between 16-minute and 2.5-hour 'Reduced Comfort Boundary' Contours

Frequency, Hz	1	3	5	7	9	11	13	17
ISO 2631 (1974) (in %)	66	66	66	66	66	66	66	66
Current Findings (in %)	33	52	50	47	66	65	57	56

a_y axis Excitation. Percentage Deviation in RMS 'g' Level Between 16-minute and 2.5-hour 'Reduced Comfort Boundary' Contours

Frequency, Hz	1	3	5	7	9	11	13	17
ISO 2631 (1974) (in %)	66	66	66	66	66	66	66	66
Current Findings (in %)	54	62	63	52	55	62	57	70

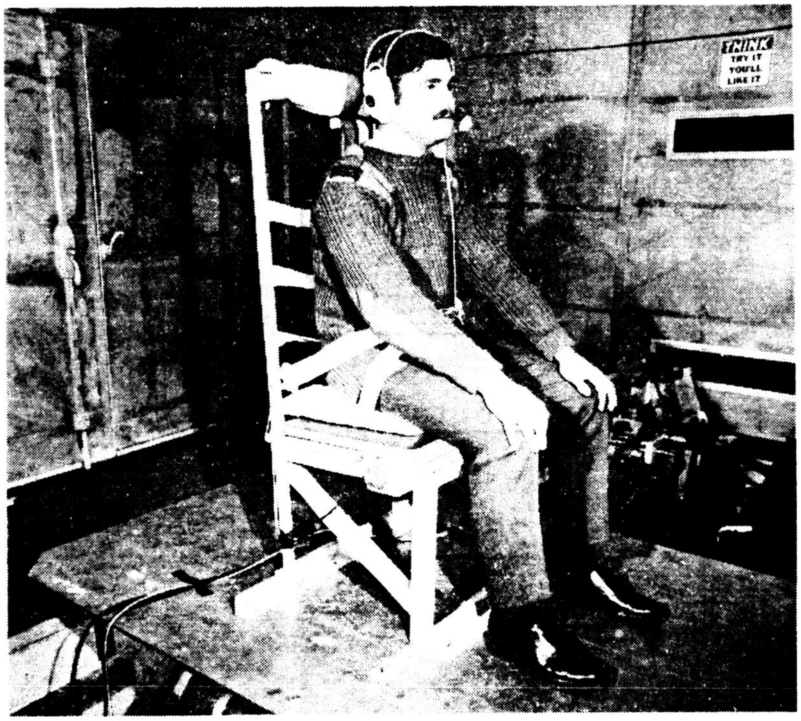


Plate 1.- Subject posture.

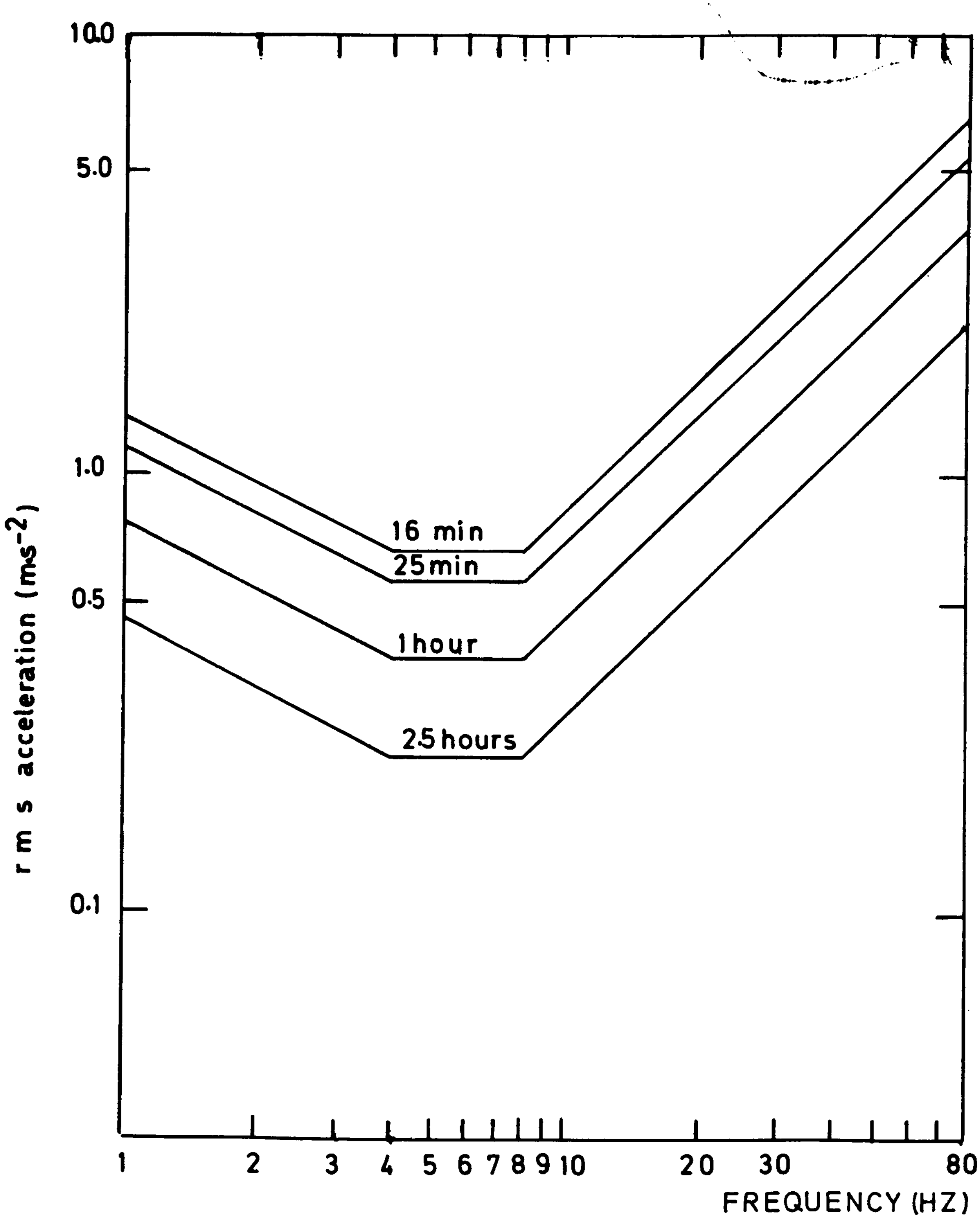


Figure 1.- Reduced comfort boundary (a_z).

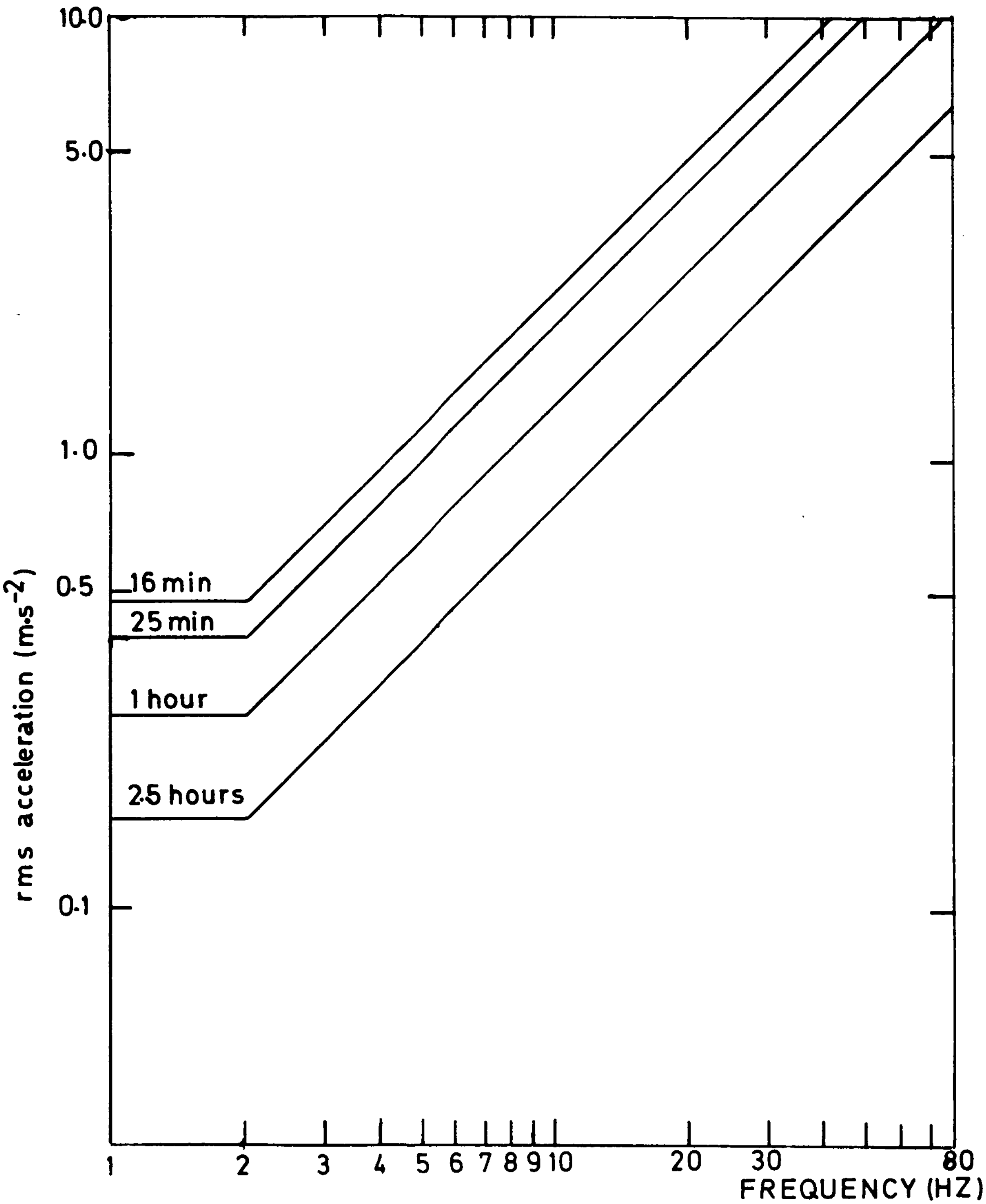
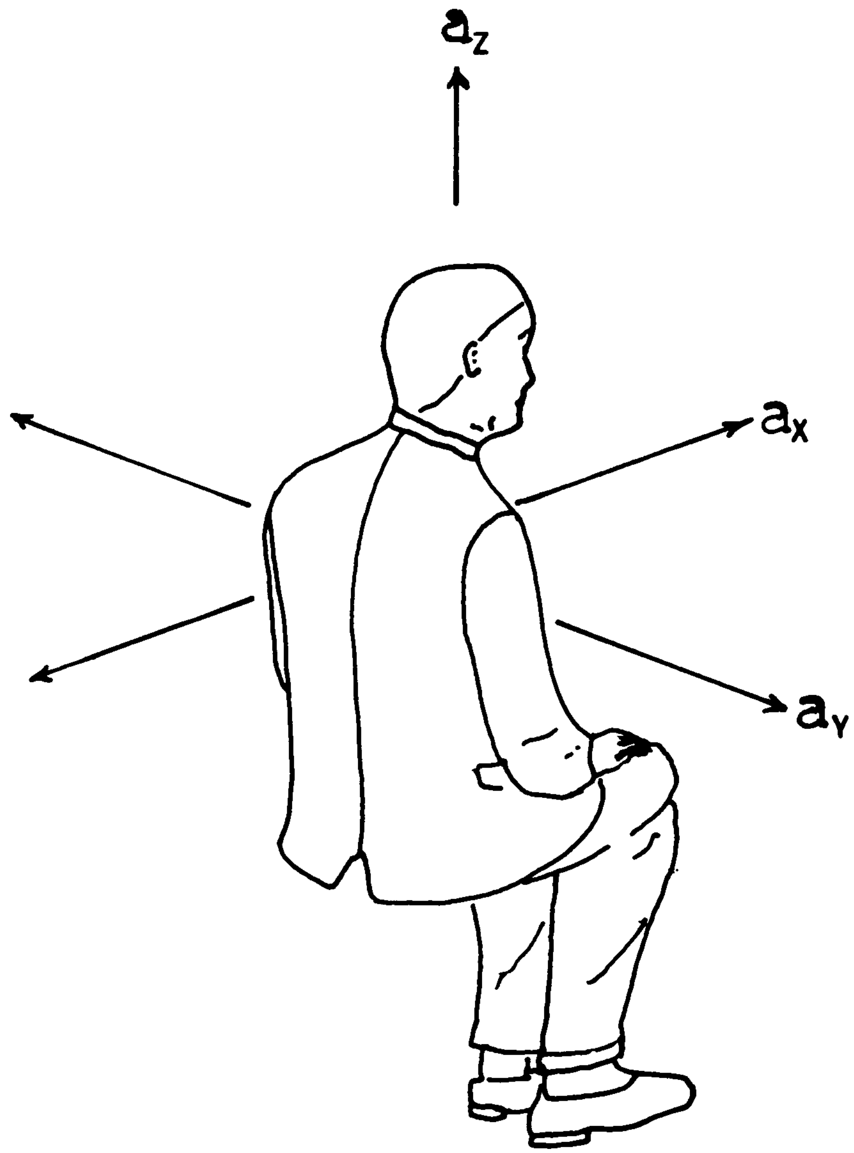


Figure 2.- Reduced comfort boundary (a_x and a_y).



a_x ,a_y ,a_z	= acceleration in the directions of the x,y,z axes
x axis	= back-to-chest
y axis	= right-to-left side
z axis	= foot-to-head

Figure 3.- Coordinate system for mechanical vibrations influencing humans.

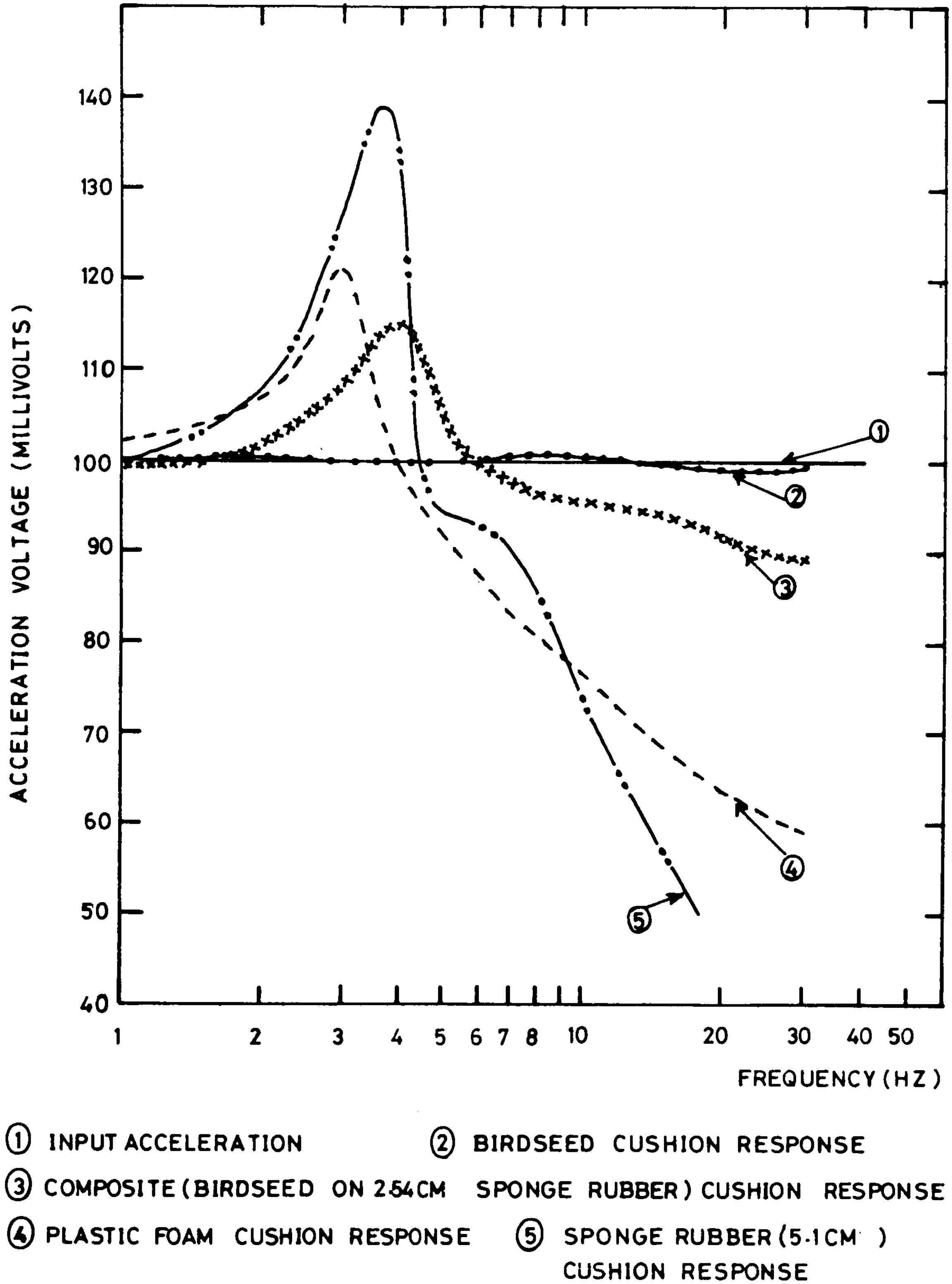


Figure 4.- Dynamic response of cushions at subject-seat interface.

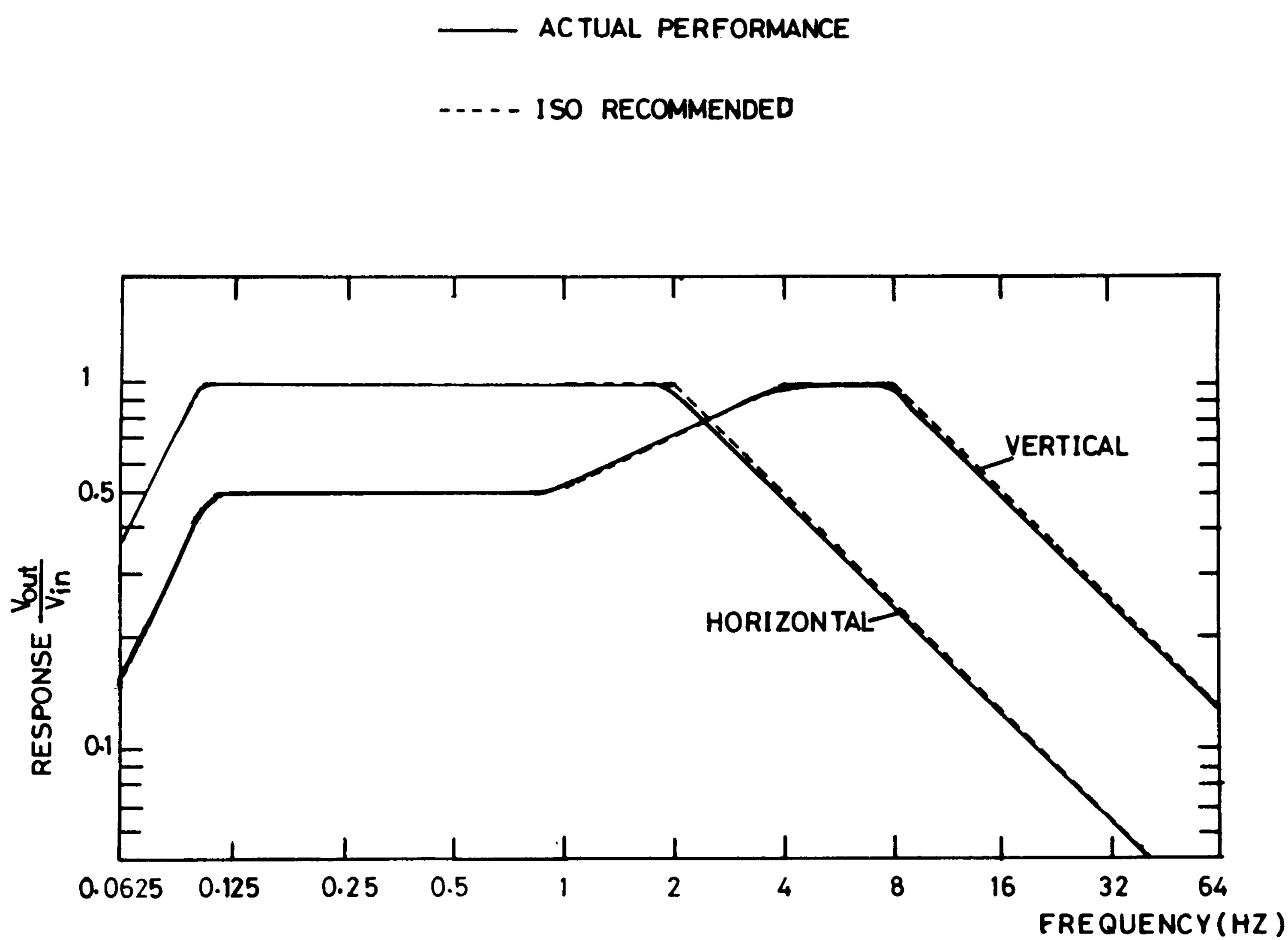


Figure 5.- Weighting filter characteristics.

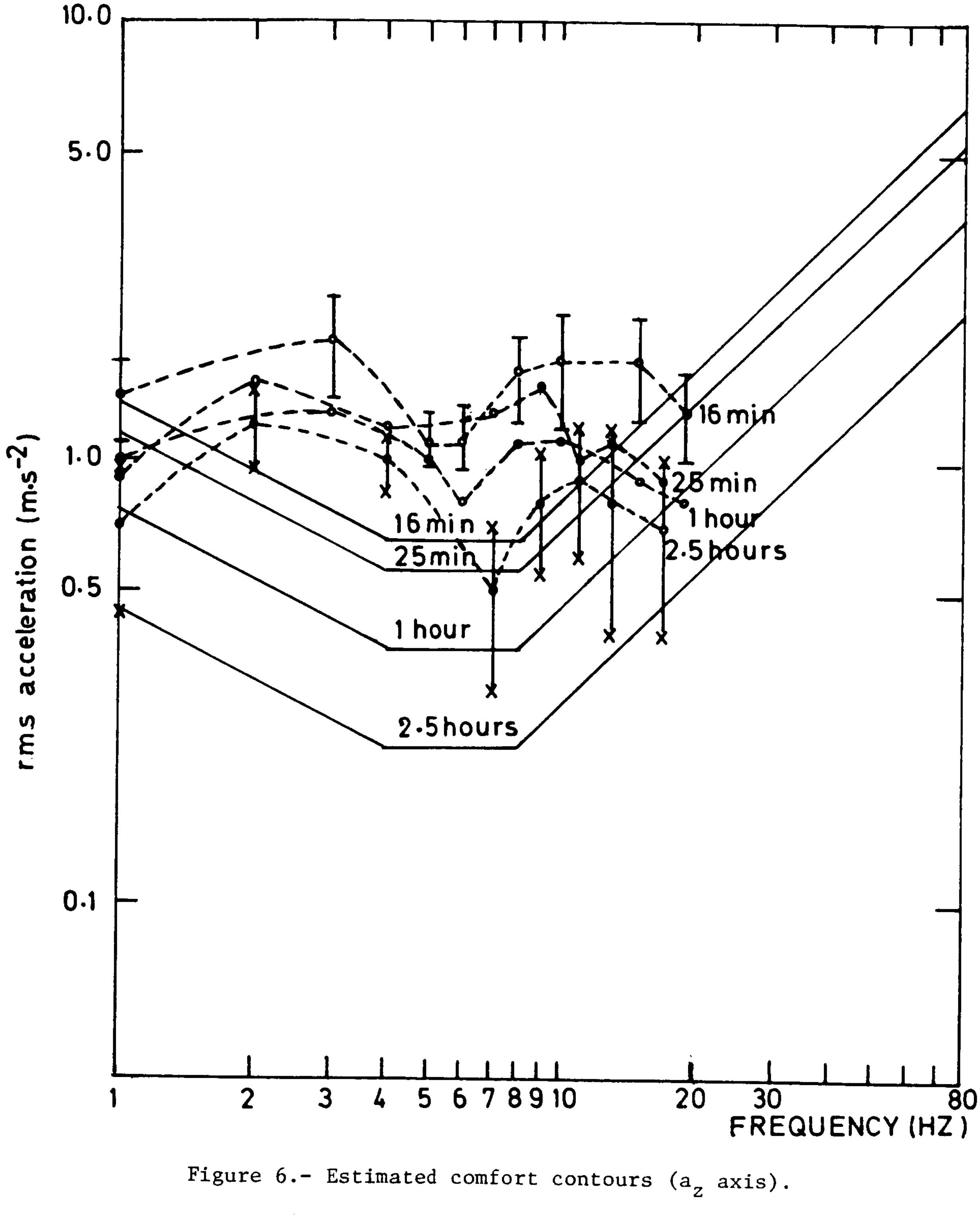


Figure 6.- Estimated comfort contours (a_z axis).

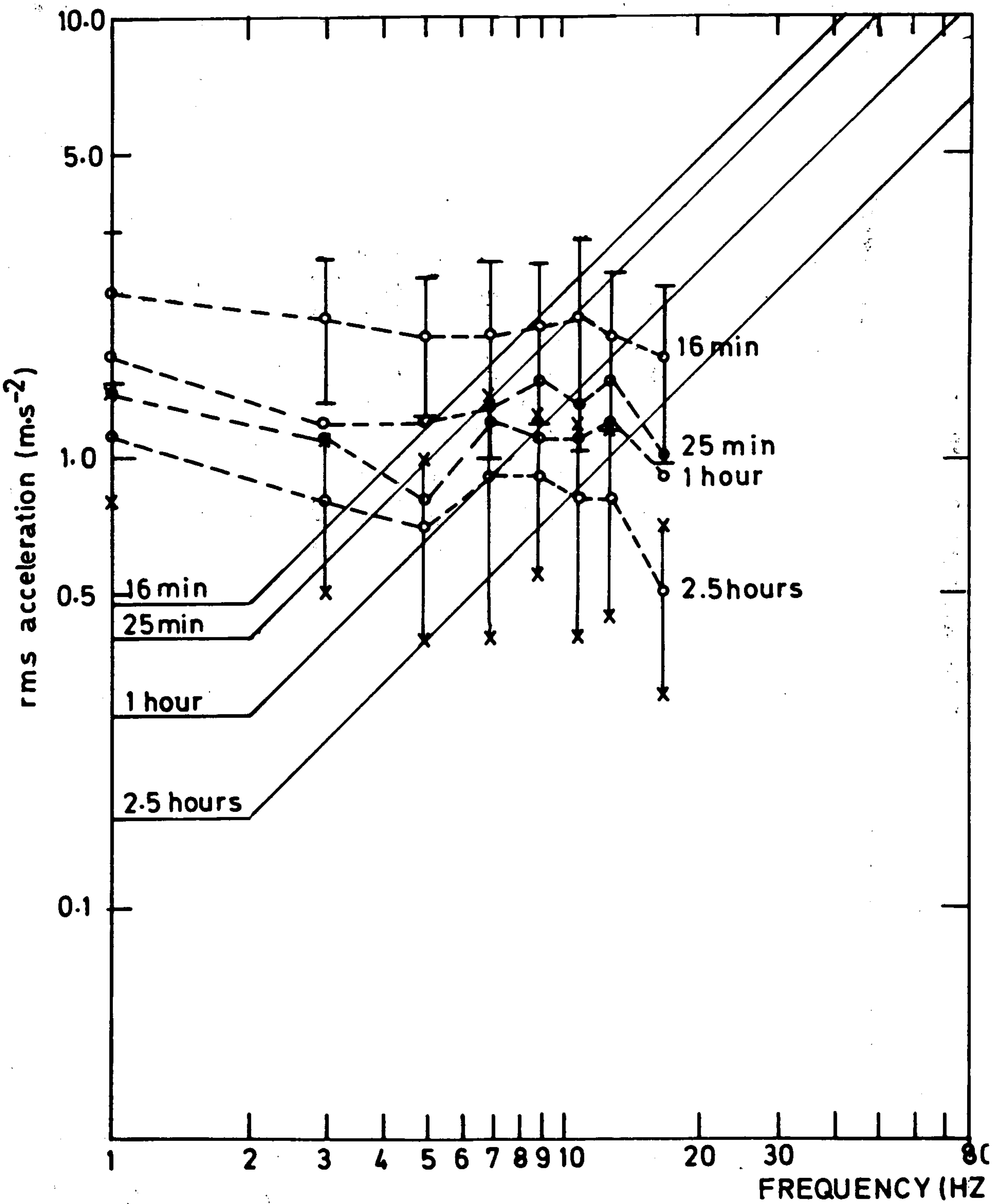


Figure 7.- Estimated comfort contours (a_y axis).

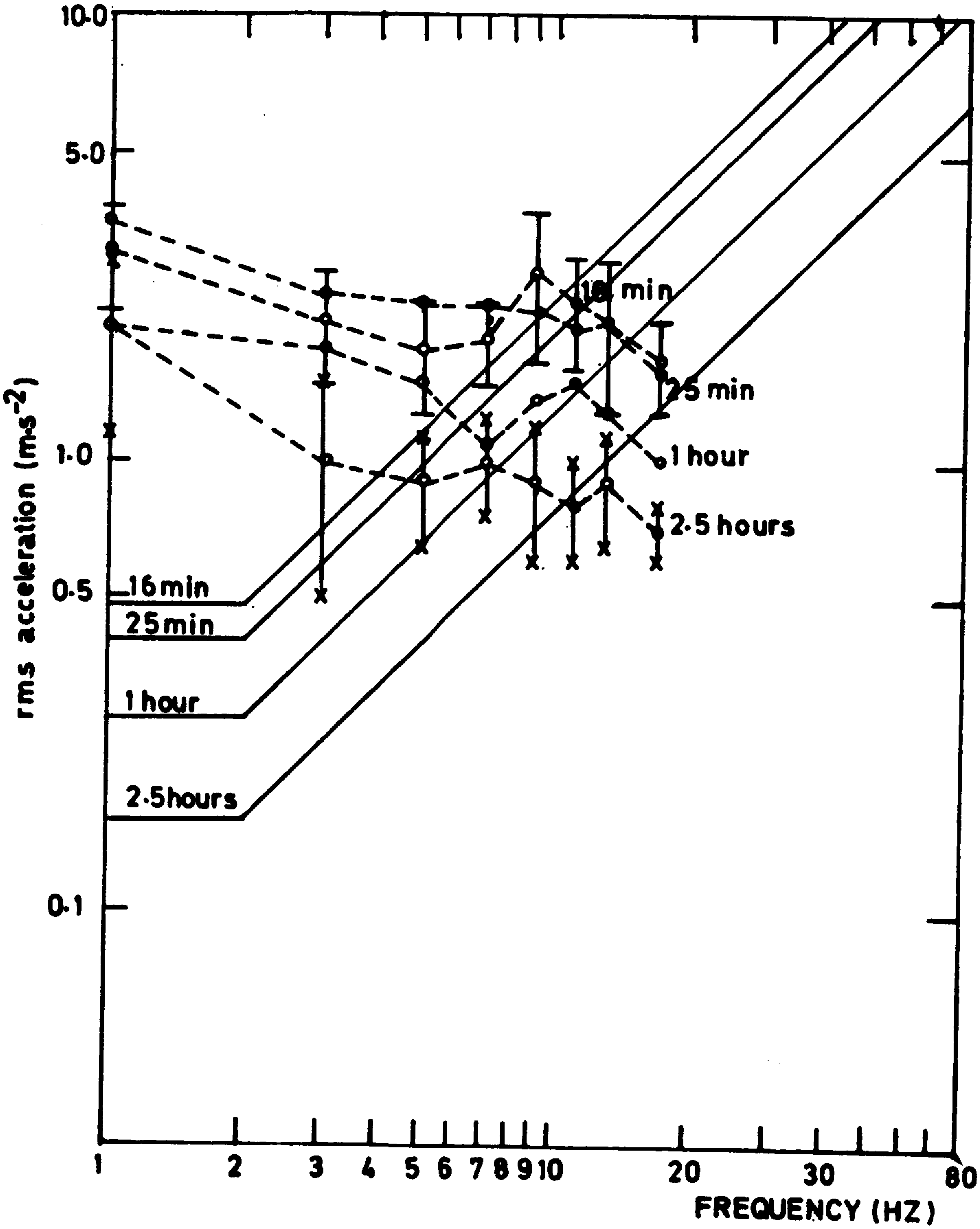


Figure 8.- Estimated comfort contours (a_x axis).

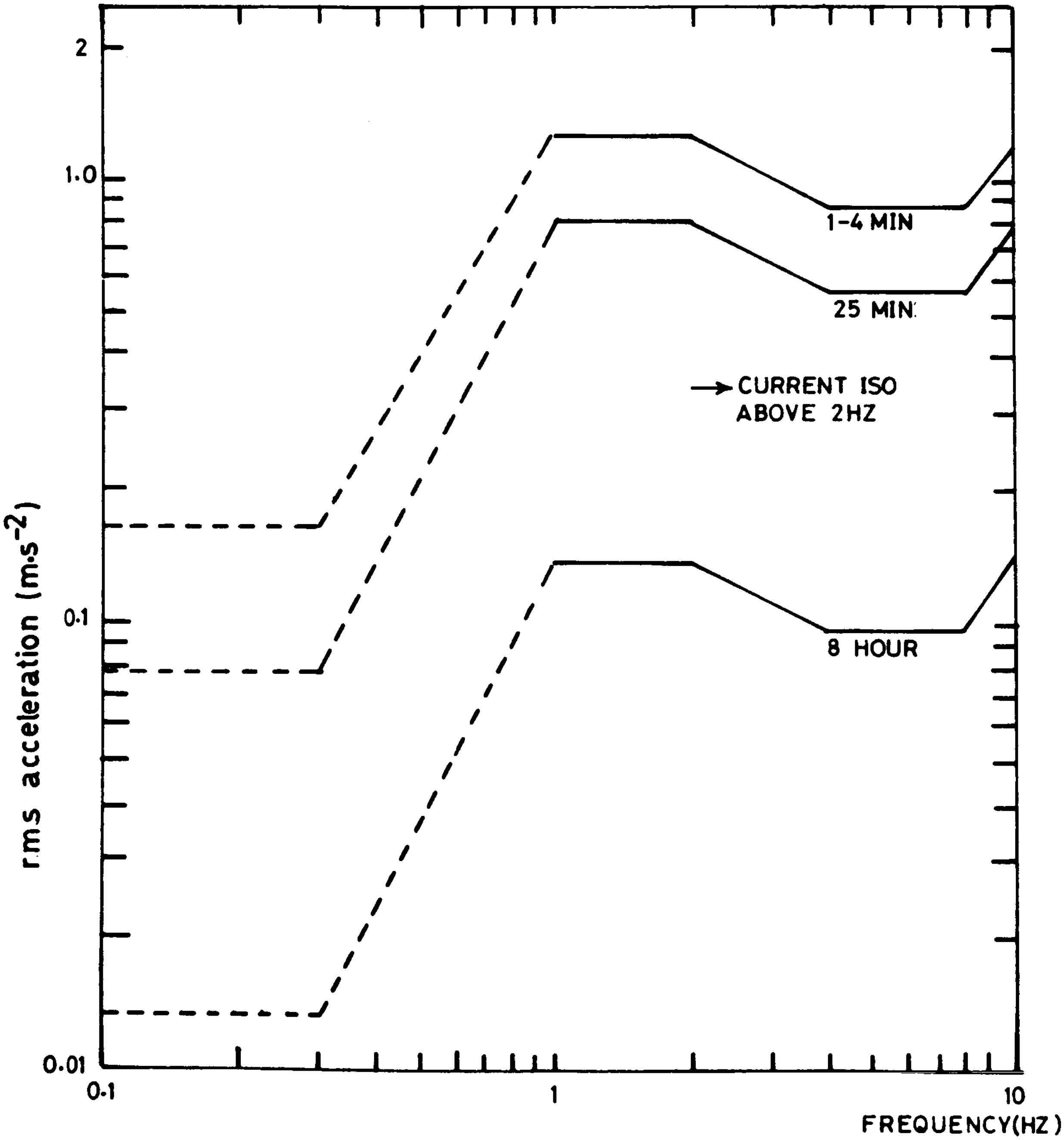


Figure 9.- Proposed vertical vibration reduced comfort boundary >0.1 Hz.

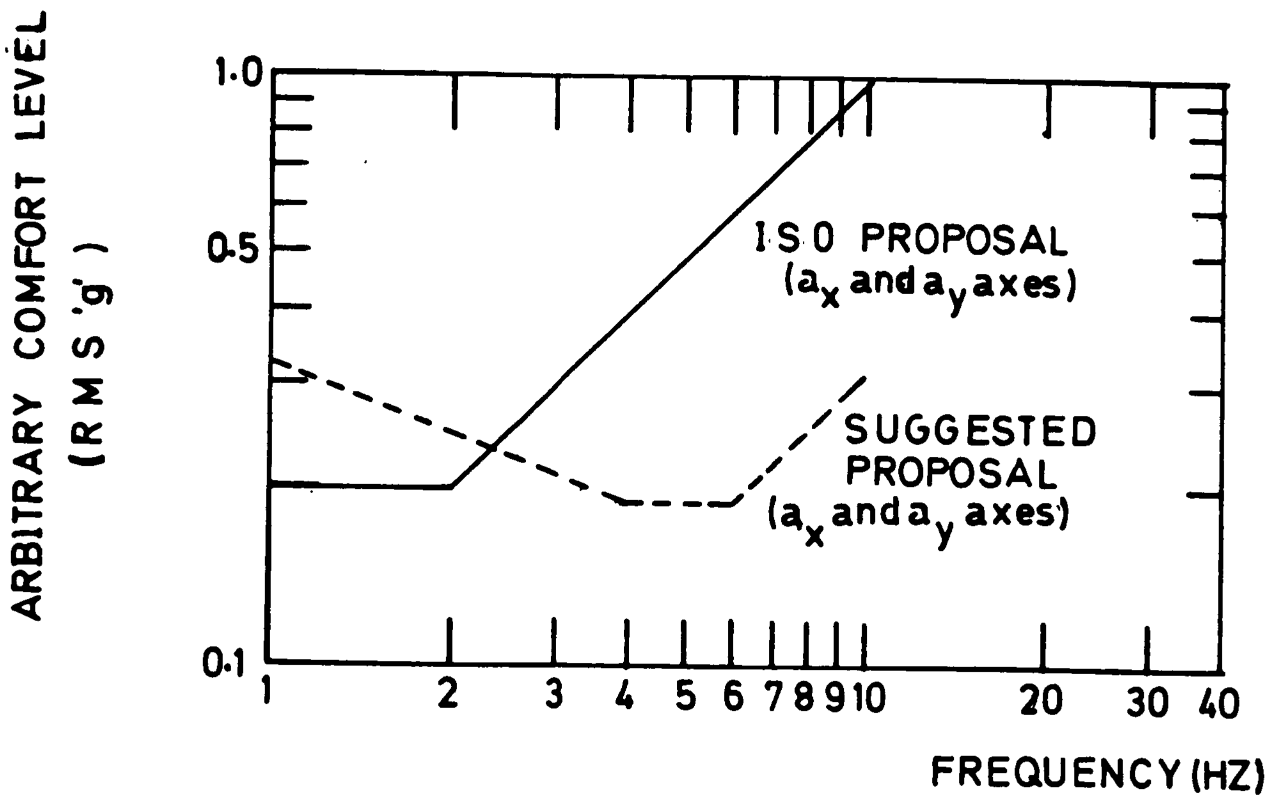


Figure 10.- A suggested contour shape for a_x, a_y axes response.