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AN EXPERIMENTAL STUDY FOR DETERMINING HUMAN DISCOMFORT RESPONSE TO ROLL VIBRATION

Jack D. Leatherwood, Thomas K. Dempsey, and Sherman A. Clevenson

Langley Research Center
Hampton, Va. 23665

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16. Abstract

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SUMMARY

An experimental study using the Langley passenger ride quality apparatus (PRQA) was conducted to determine the subjective reactions of passengers to roll vibrations. The data obtained illustrate the effect upon human comfort of several roll-vibration parameters: namely, roll-acceleration level, roll frequency, and seat location (i.e., distance from axis of rotation). Results of an analysis of variance indicated that seat location had no effect on discomfort ratings of roll vibrations. The effect of roll-acceleration level was significant, and discomfort ratings increased markedly with increasing roll-acceleration level at all roll frequencies investigated. Of particular interest is the fact that the relationship between discomfort ratings and roll-acceleration level was linear in nature. The effect of roll frequency also was significant as was the interaction between roll-acceleration level and roll frequency. Thus, the prediction of discomfort response to roll vibration requires knowledge of both roll-acceleration level and roll frequency. Other interactions of the roll parameters were not significant.

INTRODUCTION

The development of a comprehensive model to describe and predict passenger comfort response to multidegree-of-freedom vibratory motion is the objective of a research program at the NASA Langley Research Center. Such a model could be used as a predictor of ride quality (discomfort) in new or advanced transportation systems and also as a diagnostic tool to determine the source of discomfort of an unsatisfactory ride. The model itself is outlined in detail in reference 1. Several experimental studies oriented toward the development of this model have been conducted and reported in references 2 to 7. These investigations thus far have been restricted to the vertical-and-lateral degrees of freedom and have been concerned with such factors as experimental methodology (refs. 2, 3, and 4), the psychophysical relationships governing human discomfort response to vertical vibration stimuli (ref. 5), and the systematic development of constant discomfort contours (refs. 6 and 7). None of the aforementioned studies has been concerned with angular vibrations such as those associated with the roll and pitch degrees of freedom. In fact, a recent survey of the literature on environmental criteria for human comfort (ref. 8) specifically noted a lack of data on subjective response to angular motions. Obviously such motions are present in almost all transportation system vehicles. Some examples of measured levels of roll acceleration are given in reference 9 (1.5 rad/sec^2 in roll for a B-52 airplane) and in reference 10 (up to 2.0 rad/sec^2 for personal rapid transit vehicles). It is not apparent at the present time just what role these angular motions play in human assessment of ride comfort.

It is the purpose of this paper to explore human comfort response to roll vibrations, specifically, the effect upon human comfort of the roll vibration factors of frequency and roll-acceleration level. In addition, the effect of seat location (i.e., distance from the axis of rotation) on comfort responses within the particular test apparatus used in this study will be discussed. The results provide necessary information for development of the predictive model.

SYMBOLS

df	statistical degrees of freedom
f	roll frequency, Hz
F	F statistic or F ratio
p	probability
R	roll-acceleration level, rad/sec^2
t	t statistic or t-test

Randomization without replacement is the process of randomly selecting elements of a set without replacing the element after each selection.

TEST APPARATUS

The apparatus used in this study is the three-degree-of-freedom motion simulator called the passenger ride quality apparatus (PRQA) located at the NASA Langley Research Center. The simulator is described in detail in reference 11 and the reader is referred to that reference for information related to system operation, capabilities, and design. For this investigation, only the roll degree of freedom was studied and the capabilities of the PRQA for producing roll accelerations are given in figure 1. Note that the maximum angular accelerations (rad/sec^2) obtainable are approximately 6.3 rad/sec^2 over the frequency range of 1.3 to 5 Hz. Below a frequency of 1.3 Hz the system response is limited by the displacement capabilities of the actuators to ±0.1 rad. Photographs of PRQA and associated programing and control instrumentation are displayed in figure 2. Figure 2(a) shows the waiting room where subjects were instructed as to their participation in the experiment, completion of questionnaires, and so forth. Shown in figure 2(b) is a model of PRQA indicating the supports, actuators, and restraints of the three-axis drive system. A photograph of the exterior of the PRQA is presented in figure 2(c) and it should be noted that the actual mechanisms which drive the simulator are located beneath the pictured floor.

An interior view of PRQA with the subjects seated in first-class aircraft seats (tourist aircraft seats were used in the present study) is presented in figure 2(d). The control console is shown in figure 2(e) and is located at the same level as the simulator to allow the console control operator to constantly monitor subjects within the simulator. Figure 2(f) is a photograph of tourist aircraft seats used.

EXPERIMENTAL METHOD

Subjects

A total of 72 subjects (42 males, 30 females) participated in this study. The subjects were undergraduate students from Old Dominion University and were paid for their participation in the investigation. The ages of the subjects ranged from 18 to 45 years, with a median age of 20 years. The mean weight of the subjects was 143.2 pounds (65 kg), with a standard deviation of 24.4 pounds (11.1 kg).

Subjective Evaluation Scale

A nine-point unipolar scale, with associated numerical integers, was used by each subject to evaluate the discomfort of a vibration. The scale was anchored at zero with the words "Comfortable" or "Zero Discomfort." The anchor at the opposite end of the scale was "Maximum Discomfort." Thus, the scale continuum of increasing numbers was interpreted as representing increasing degrees of discomfort. The subjects were instructed to interpret the scale in an equal-interval fashion. The subjects were further instructed to base evaluations upon the discomfort of vibrations rather than upon the detection of intensity level differences. The actual subject instructions and rating scales are given in the appendix. Prior to the application of the stimuli for each session the subjects were exposed to low-discomfort and high-discomfort vibrations, and they were directed to use these as the anchor points most people would apply to the opposite ends of the rating scale. The low-discomfort vibration was 2 Hz at 0.48 rad/sec^2 and the high-discomfort vibration was 1 Hz at 2.88 rad/sec^2.

Test Procedure

The task for each subject (six subjects concurrently) was an evaluation of successive "ride segments." A "ride segment" is defined as a vibration at one of four roll frequencies (1 to 4 Hz) and at one of four levels of roll acceleration (0.48, 0.96, 1.92, and 2.88 rad/sec^2). The ride segments lasted for 10 sec with an additional rise and decay duration of 3 sec each, and an inter-stimulus interval of 3 sec. The rise and decay portion of each stimulus was achieved with the use of an electronic circuit which provided a ramp function onset and offset of the simulator drive signal. Through the use of a two-way auditory communication system, the subjects were instructed when to begin evaluation by the word "start" and when to end the evaluation by the word "stop." The subjects were directed to ignore rise and decay vibrations that occurred prior and subsequent to the words "start" and "stop." The following table displays testing format of the present study:

	Session			
Ride segment	1	2	3	4
1				
2				
3				
4				
5				
6				
7				
8				

Each of the four roll frequencies was randomized without replacement and represented the frequency content of a session. The four roll-acceleration levels were randomized without replacement twice and represented the acceleration levels of the eight ride segments of a session. Each session lasted approximately 4 min, with a 1-min rest interval between sessions. A total of four different test sequences (i.e., randomization of roll frequencies, and roll-acceleration levels within a frequency) were used in the investigation and were repeated three times each. However, each subject (in groups of six) was exposed to only one sequence of tests, and each subject occupied the same seat location throughout testing.

RESULTS AND DISCUSSION

An analysis of variance was computed in order to provide an overall summary of the discomfort due to the three roll-vibration factors previously discussed. A three-dimensional analysis of variance (3 × 4 × 4) with repeated measures on the same subject within a seat location across levels of the last two dimensions was used to determine the effect of seat location, roll-acceleration level, and roll frequency upon discomfort responses. (See table I and ref. 12.) There were three seat locations within the first dimension, four levels of roll acceleration in the second dimension, and four levels of roll frequency within the third dimension. The inclusion of roll frequency and roll-acceleration level as variables is obvious, but the inclusion of seat location as a variable requires further explanation. The orientation of the passenger seats is illustrated in figure 3(a) as viewed from above the seats and in figure 3(b) as viewed from a position in front of the seats. In the sketch presenting the top view, the seats are labeled in pairs as row 1 (window seats), row 2 (center seats), and row 3 (aisle seats). Figure 3(b) shows the center of rotation for the roll axis and the approximate distances to the heads of subjects seated front or rear in each of the three rows. Obviously, subjects seated in each of the three locations will experience some differences in tangential-and-radial acceleration due to the differences in distance from the axis of rotation. Whether or not these differences in acceleration give significant differences in a passenger's response is discussed in the following sections.

An overall summary of the results of the analysis of variance is given in table II. The results presented in the last column (F ratio column) indicate that the effect of seat location is not significant, whereas the effects of roll-acceleration level and roll frequency, as well as their interaction, are significant. Each of the three main effects - seat location, roll-acceleration level, and roll frequency - is discussed in the following sections in more detail.

Seat Location

As mentioned earlier, the effect of seat location on subjective evaluations was not significant for the particular seat arrangement and roll axis used in this study. The overall effect of seat location is illustrated in figure 4 which shows the mean discomfort rating (averaged over roll frequency and roll-acceleration level) plotted as a function of seat location. Inspection of this figure revealed very little effect of seat location as pointed out earlier in the discussion of the results of the analysis of variance. Despite the fact that the overall effect of seat location was not significant, it was decided to test the a priori hypothesis that differences in comfort ratings would be greater between aisle and window seat locations (or between window and center seat locations) than between the aisle and center locations. To test this hypothesis, t-test values were computed between the comfort ratings for different seat locations, because of the possibility that such differences could be hidden by the data averaging procedures used in the analysis of variance. None of these t-test comparisons were significant: t-values = 0.5691, 0.5411, and 1.0991; degrees of freedom = 766 for window vs center, window vs aisle, and center vs aisle comparisons, respectively, with $-1.960 \geq$ t-value ≥ 1.960 needed to achieve significance at the $p < 0.05$ level. These findings indicated no apparent difference between seat locations. These results must, however, be qualified by the fact that many vehicles may be configured differently than the test cabin used in this study and, consequently, the passengers could be located at different distances from the roll axis as well as experience different levels of roll acceleration. Thus, these results are not intended to be construed as general results but are restricted to the particular cabin geometry and roll vibrations studied herein. The authors feel though that the configuration and the roll-vibration environment are representative of many existing transport vehicles.

Roll Acceleration

The second main effect of interest or roll acceleration was significant as indicated by the data in table II. This effect is displayed in figure 5 which shows the mean discomfort ratings (averaged over seat location and roll frequency) as a function of roll-acceleration level. This figure shows that discomfort ratings increase markedly as roll-acceleration level increases. Table III is a summary of t-test comparisons between the discomfort ratings of the different roll-acceleration levels given in table I, and all comparisons were found to be significant. It should be noted that the relationship between mean discomfort rating and roll-acceleration level appears to be highly linear in nature. This finding is similar to that of previous work (see ref. 5) which indicated a linear relationship between vertical acceleration level and magnitude estimations of subjective discomfort.

Roll Frequency

The third main effect considered in the analysis of variance was that of roll frequency which was also a significant effect, as the data in table II show. Figure 6 presents the mean discomfort rating (averaged over seat location and roll-acceleration level) for each of the roll frequencies investigated. To determine if ratings varied with frequency, t-test comparisons were made between each pair of frequencies, and the t values are given in table IV. Statistically significant differences in discomfort response occurred between all frequency pairs except frequencies of 1 and 2 Hz.

Roll-acceleration-level and roll-frequency interaction.- The analysis of variance indicated a significant interaction between roll-acceleration level and roll frequency. (See table II.) This interaction is displayed graphically in figure 7 which shows the mean discomfort rating (averaged over seat location) as a function of roll-acceleration level for each frequency of roll vibration. This figure is simply a breakdown of figure 5 into its roll-frequency components and it is seen that the trend illustrated in figure 5 holds for each individual frequency. A summary of t-test comparisons between the discomfort rating of each frequency and at each level of roll acceleration is presented in table V. Significant differences between frequencies did occur for a large number of the frequency pairs tested. Note in particular that at the highest level of roll acceleration all frequency pairs demonstrated significant differences. Figure 8 illustrates the roll-acceleration-level and roll-frequency relationship in a format that displays the effect of changes in roll-acceleration level at each frequency on the mean discomfort rating. This figure is a decomposition of figure 6 into its roll-acceleration-level components. Once again the effect of roll-acceleration level is readily apparent. The t-test comparisons between discomfort rating for each level of roll acceleration at each frequency are given in table VI and were all significant ($p < 0.05$). The implication of these results is that a prediction of the discomfort contribution due to the roll component of motion present in a vehicle will require knowledge of roll frequency, roll-acceleration level, and their interaction.

Other interactions.- The interaction between seat location and roll-acceleration level was not significant. (See table II; F ratio = 1.08.) This lack of interaction is shown in figure 9 which presents the mean discomfort rating as a function of roll-acceleration level for each seat location. Although the graph shows some spread between the points at each roll-acceleration level for each seat location, these differences are not statistically significant. The relationships between seat location and roll frequency are illustrated in figure 10. Again, the interaction between these two factors was not significant. (See table II; F ratio = 1.65.) It should be kept in mind that these results are specific to the simulator (PRQA) used in this study.

CONCLUDING REMARKS

An experimental investigation was conducted to determine human discomfort response to roll vibrations and, specifically, to investigate possible interactions between roll frequency, roll-acceleration level, and passenger seat location. The data indicated that seat location had no significant effect on discomfort response rating of roll vibrations. This result, however, is based upon data obtained from the particular cabin configuration used in this study and generalization to other configurations with different roll-axis locations may or may not be appropriate. The effect of roll-acceleration level was significant with discomfort rating increasing markedly at all roll frequencies investigated as roll-acceleration level increased. Of particular note was the linear nature of the relationship between discomfort rating and roll-acceleration level. Such a relationship is in full agreement with the psychophysical relationship previously determined for human discomfort response to translational accelerations in the vertical axis. The demonstration of such a linear relationship should greatly facilitate the development of ride-quality criteria. The effect of roll frequency also was statistically significant for all roll-frequency pairs except between frequencies of 1 and 2 Hz. This finding, combined with the significant interaction occurring between roll-acceleration level and roll frequency, implies that prediction of discomfort response to roll vibration requires knowledge of both roll-acceleration level and roll frequency. Finally, the results indicate that the other interactions (seat location and roll-acceleration level, and seat location and frequency) were not significant and therefore of no particular concern in the development of ride-quality criteria for vehicles configured similarly to the one used in this study.

Langley Research Center
National Aeronautics and Space Administration
Hampton, VA 23665
August 30, 1976

APPENDIX

SUBJECT INSTRUCTIONS

You have volunteered to participate in a research program to investigate the quality of rides. Specifically, we wish to identify the types of vibration in transportation vehicles which most influence a person's sense of well-being. To assess the influence of these vibrations, we have built a simulator which can expose passengers to realistic ride motions. The simulator essentially provides no risk to passengers. The system has been designed to meet stringent safety requirements such that it cannot expose subjects to motions which are known to cause injury. It contains many built-in safety features which automatically shut the system down if it does not perform properly.

The vibrations that you will receive today are representative of the vibrations you may experience in an airplane. You will enter the simulator, take a seat, fasten the seatbelt, and assume a comfortable position with both feet on the floor. Selected vibrations will then be applied to the cabin. You are to make yourself as comfortable and relaxed as possible while the test is being conducted. However, you must keep your feet on the floor and keep your seatbelts fastened at all times. During the tests you will at all times be in two-way communication with the test conductor.

You have the option at any time and for any reason to terminate the tests in any one of three ways: (1) by pressing overhead button labeled "stop," (2) by voice communication with the test conductor, or (3) by unfastening your seatbelt. Because of individual differences in people, there is always the possibility that someone may find the motions objectionable and may not wish to continue. If this should happen to you, please do not hesitate to stop the tests by one of the methods above.

The task you will be required to perform is to evaluate the discomfort associated with various ride segments. Each ride segment, to be evaluated by yourself, will be presented to you for a total of 20 seconds. I will specify the start of a ride segment with the word "start," and I will specify the end of a ride segment with the word "stop." Evaluate the discomfort of a <u>vibration</u> contained in a ride segment in terms of the following discomfort scale:

ZERO DISCOMFORT								MAXIMUM DISCOMFORT
0	1	2	3	4	5	6	7	8

APPENDIX

There will be several seconds between successive ride segments to allow you to mark your evaluation of discomfort.

Evaluation marks.- You should record your evaluation of the discomfort (associated with the vibration of each ride segment) by placing a checkmark (e.g., ✓) upon the scale continuum. Try to be careful in recording your evaluations because the point of the checkmark (✓) will be used for interpretation of distance along the scale.

Scale interpretation.-

The discomfort scale should be interpreted as if equal numerical distances represented equal discomfort. For example, the magnitude of discomfort between 1 and 2 is equal to the magnitude of discomfort between 5 and 6. The total continuum should be conceived as representing increasing discomfort values (smallest to greatest) you may associate with vibration. In addition, it should be emphasized that your evaluation of discomfort should be based only upon vibration. Certainly, you could evaluate the discomfort of a ride segment based upon other factors as temperature, pressure, etc. However, restrict your discomfort evaluations to variations of vibration.

The scale will be more meaningful when you are given several practice ride segment vibrations. The practice segments will contain representative vibrations that could be evaluated along the discomfort continuum. You will be given a total of two practice ride segments.

Consistency.- It is typical for participants in the study to "try and be consistent." Instead of trying to be consistent with previous ride segments, try and evaluate each segment without looking at evaluations of previous ride segments. Please do not be concerned about whether your ratings agree with the others in the simulator with you. Remember we want to know how different people feel about the ride. You may talk between the segments you are to rate, but please do not talk during them. It is also typical for participants to feel that they are not doing well at this task. It is usually true, however, that participants are doing better than they think they are, so don't be discouraged if you find the task difficult or monotonous at times.

Remember.-

1. Listen for the words "start" and "stop."

2. Evaluate the vibration of each ride segment in terms of the discomfort you associate with such a ride.

3. Interpret the discomfort scale as if equal numerical distances represent equal discomfort magnitudes.

4. Carefully place your evaluation mark on the continuum.

Are there any questions?

(Upon entering the simulator, the subject should be told:)

Please be seated and fasten your seatbelt. (Wait until all the subjects are ready.) Now, the mirror you see in front of you is a one-way mirror, and as I told you before, the test conductor will be able to hear everything you say. Also, if you wish to end the test, you can undo your seatbelt, press one of these little buttons (point to both), or you can ask the test conductor to stop the test and let you out.

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TABLE I.- EXPERIMENTAL DESIGN SHOWING ROLL-ACCELERATION LEVELS, ROLL FREQUENCIES, AND SUBJECT GROUPINGS

Roll-acceleration level, rad/sec^2 . . .		0.48	0.96	1.92	2.88
Roll frequency, Hz		1,2,3,4	1,2,3,4	1,2,3,4	1,2,3,4
Seat location	Subjects				
Aisle Center Window	1-24 25-48 49-72	Repeated measure on roll-acceleration level and roll frequency			

TABLE II.- SUMMARY OF THE ANALYSIS OF VARIANCE OF DISCOMFORT RATINGS

Source of variation	Sum squares	Degrees of freedom	Mean squares	F ratio (a)
Between subjects	605.11	71		
Seat location	20.87	2	10.44	1.2334 (3.15)
Subjects within groups (error: seat location)	584.24	69	8.47	
Within subjects	5599.34	1080		
Roll-acceleration level	4655.09	3	1551.70	1350.38* (2.65)
Roll-acceleration-level and seat-location interaction	7.48	6	1.25	1.08 (2.14)
Roll-acceleration-level and subject within groups (error: roll-acceleration level)	237.86	207	1.15	
Roll frequency	61.31	3	20.44	15.36* (2.65)
Seat-location and roll-frequency interaction	13.16	6	2.19	1.65 (2.14)
Roll frequency and subjects within groups (error: roll frequency)	275.30	207	1.33	
Roll-acceleration-level and roll-frequency interaction	74.59	9	8.29	19.24* (1.93)
Roll-acceleration-level, roll-frequency, and seat-location interaction	7.11	18	.39	.92 (1.72)
Roll-acceleration level, roll frequency, and subjects within groups (error: roll-acceleration level and roll frequency)	267.44	621	.43	

[a]The values with asterisks were statistically significant ($p < 0.05$). The critical values of F ratio needed to achieve statistical significance are indicated in parentheses. (When necessary, these critical values were obtained from the next lower degree of freedom.)

TABLE III.- SUMMARY OF t-TESTS BETWEEN THE DISCOMFORT RATINGS OF DIFFERENT ROLL-ACCELERATION LEVELS[a]

Roll-acceleration level comparisons	t-values
$R_{0.48}$ vs $R_{0.96}$	-23.665*
$R_{0.48}$ vs $R_{1.92}$	-33.709*
$R_{0.48}$ vs $R_{2.88}$	-48.844*
$R_{0.96}$ vs $R_{1.92}$	-25.462*
$R_{0.96}$ vs $R_{2.88}$	-38.078*
$R_{1.92}$ vs $R_{2.88}$	-25.705*

[a]The values with asterisks were statistically significant ($p < 0.05$); $-2.000 \geqq$ t-test values $\geqq 2.000$ needed to achieve statistical significance for df = 71.

TABLE IV.-SUMMARY OF t-TESTS BETWEEN THE DISCOMFORT RATINGS OF DIFFERENT ROLL FREQUENCIES[a]

Roll frequency comparisons	t-values
f_1 vs f_2	0.330
f_1 vs f_3	6.145*
f_1 vs f_4	2.667*
f_2 vs f_3	5.579*
f_2 vs f_4	2.723*
f_3 vs f_4	-3.020*

[a]The values with asterisks were statistically significant ($p < 0.05$); $-2.000 \leqq$ t-test values $\geqq 2.000$ needed to achieve statistical significance for df = 71.

TABLE V.- SUMMARY OF t-TESTS BETWEEN THE DISCOMFORT RATINGS AT VARIOUS ROLL FREQUENCIES FOR EACH ROLL-ACCELERATION LEVEL[a]

Roll-acceleration level, rad/sec^2	Roll frequency comparison					
	F_1 vs F_2	F_1 vs F_3	F_1 vs F_4	F_2 vs F_3	F_2 vs F_4	F_3 vs F_4
0.48	1.587	3.863*	3.376*	2.618*	2.368*	-0.369
.96	-3.494*	.757	-.439	4.674*	3.038*	-1.411
1.92	.685	1.986	-1.992*	1.146	-2.786*	-4.107*
2.88	4.226*	10.686*	8.097*	7.503*	6.018*	-2.628*

[a]The values with asterisks were statistically significant ($p < 0.05$); $-2.000 \leqq$ t-test values $\geqq 2.000$ needed to achieve statistical significance for df = 71.

TABLE VI.- SUMMARY OF t-TESTS BETWEEN DISCOMFORT RATINGS AT VARIOUS ROLL-ACCELERATION LEVELS FOR EACH ROLL FREQUENCY[a]

Roll frequency, Hz	Roll-acceleration level comparison					
	$R_{0.48}$ vs $R_{0.96}$	$R_{0.48}$ vs $R_{1.92}$	$R_{0.48}$ vs $R_{2.88}$	$R_{0.96}$ vs $R_{1.92}$	$R_{0.96}$ vs $R_{2.88}$	$R_{1.92}$ vs $R_{2.88}$
1	-8.989*	-23.137*	-41.085*	-16.512*	-31.681*	-21.810*
2	-13.890*	-22.741*	-37.702*	-11.982*	-24.937*	-17.827*
3	-12.865*	-27.724*	-32.153*	-18.659*	-25.144*	-14.476*
4	-11.850*	-27.748*	-35.643*	-21.418*	-24.917*	-10.873*

[a]The values with asterisks were statistically significant ($p < 0.05$); $-2.000 \leqq$ t-test values $\geqq 2.000$ needed to achieve statistical significance for df = 71.

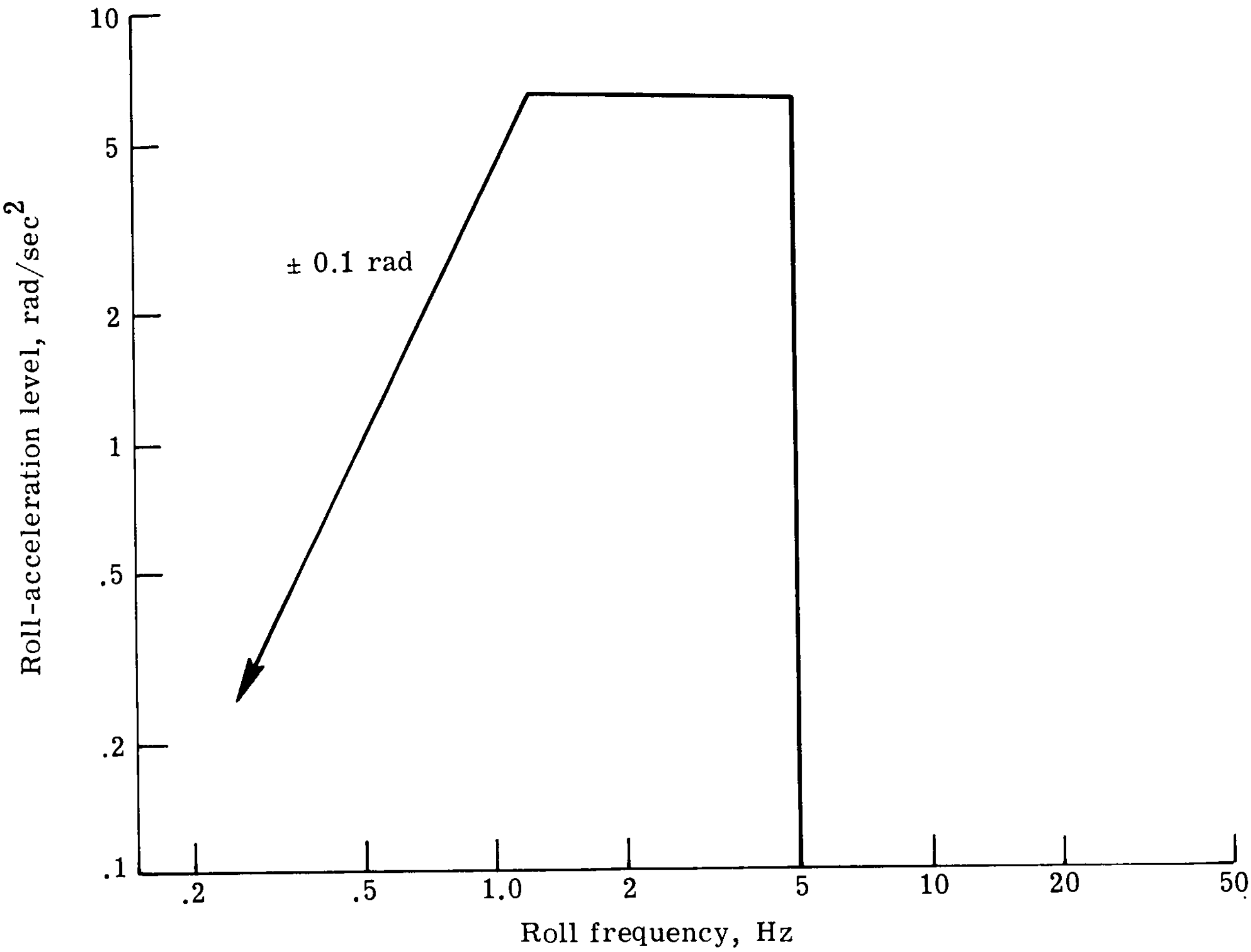
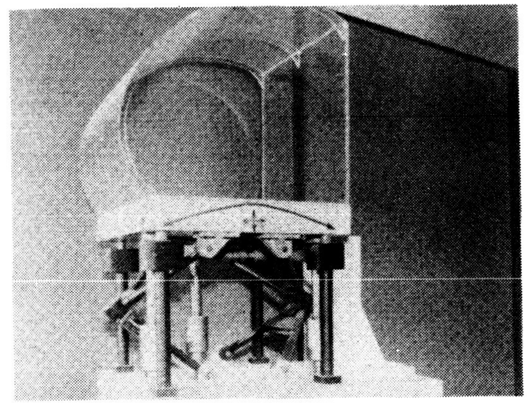
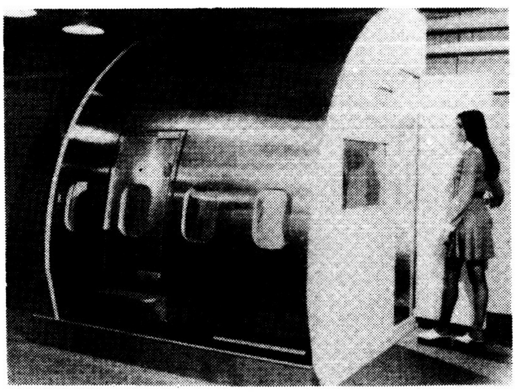


Figure 1.- PRQA capability in roll motion.

(a) Waiting room.

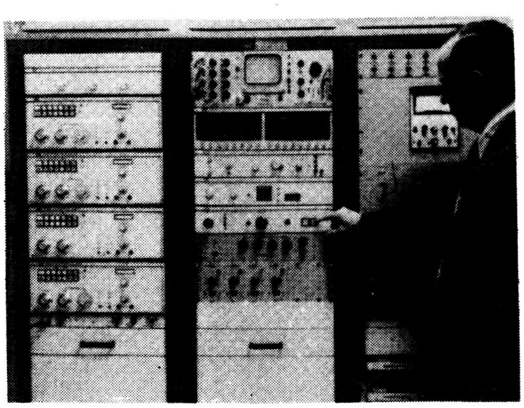


(b) Model of PRQA.

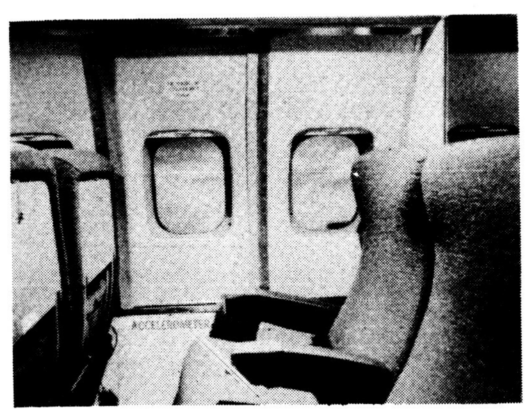


(c) Simulator exterior.

(d) Simulator interior.



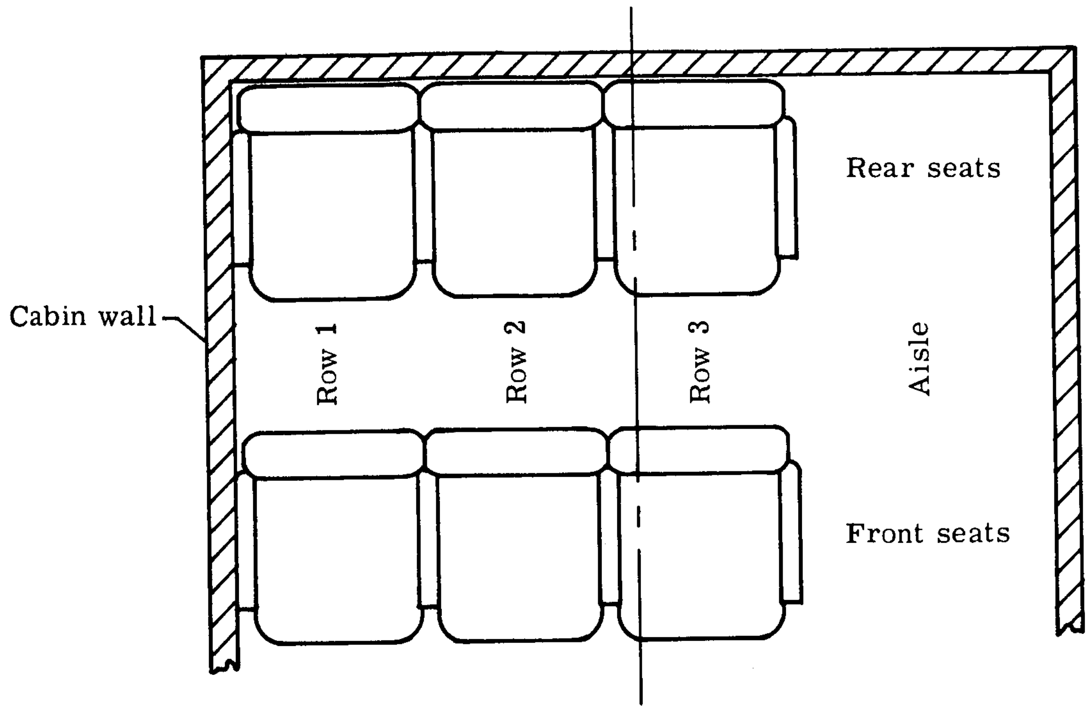
(e) Control console.



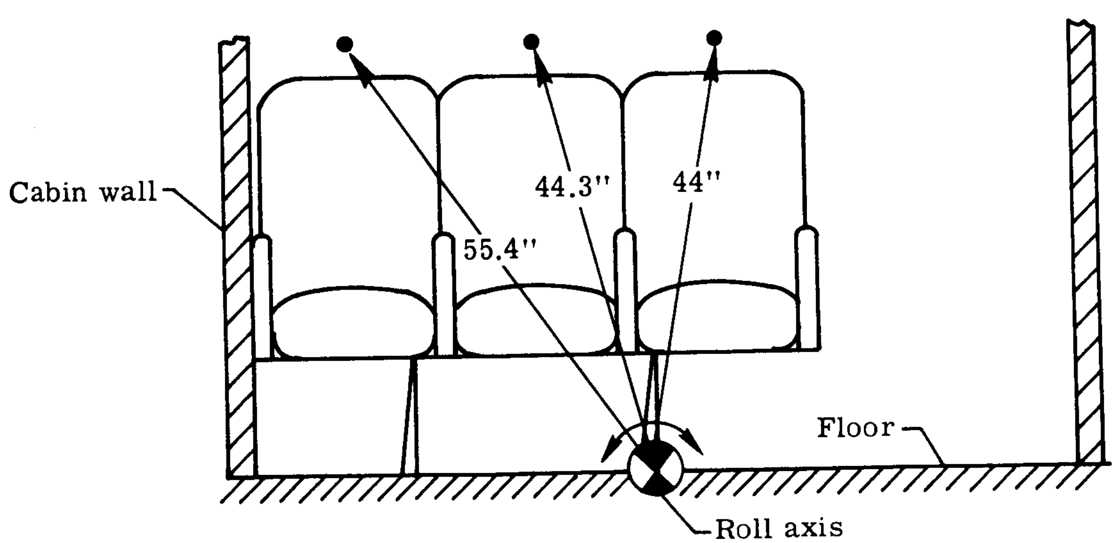
(f) Tourist-class seats.

L-75-218

Figure 2.- Langley passenger ride quality apparatus (PRQA).



(a) Top view.



(b) Front view.

Figure 3.- Seat location. (Sketch is not drawn to scale.)

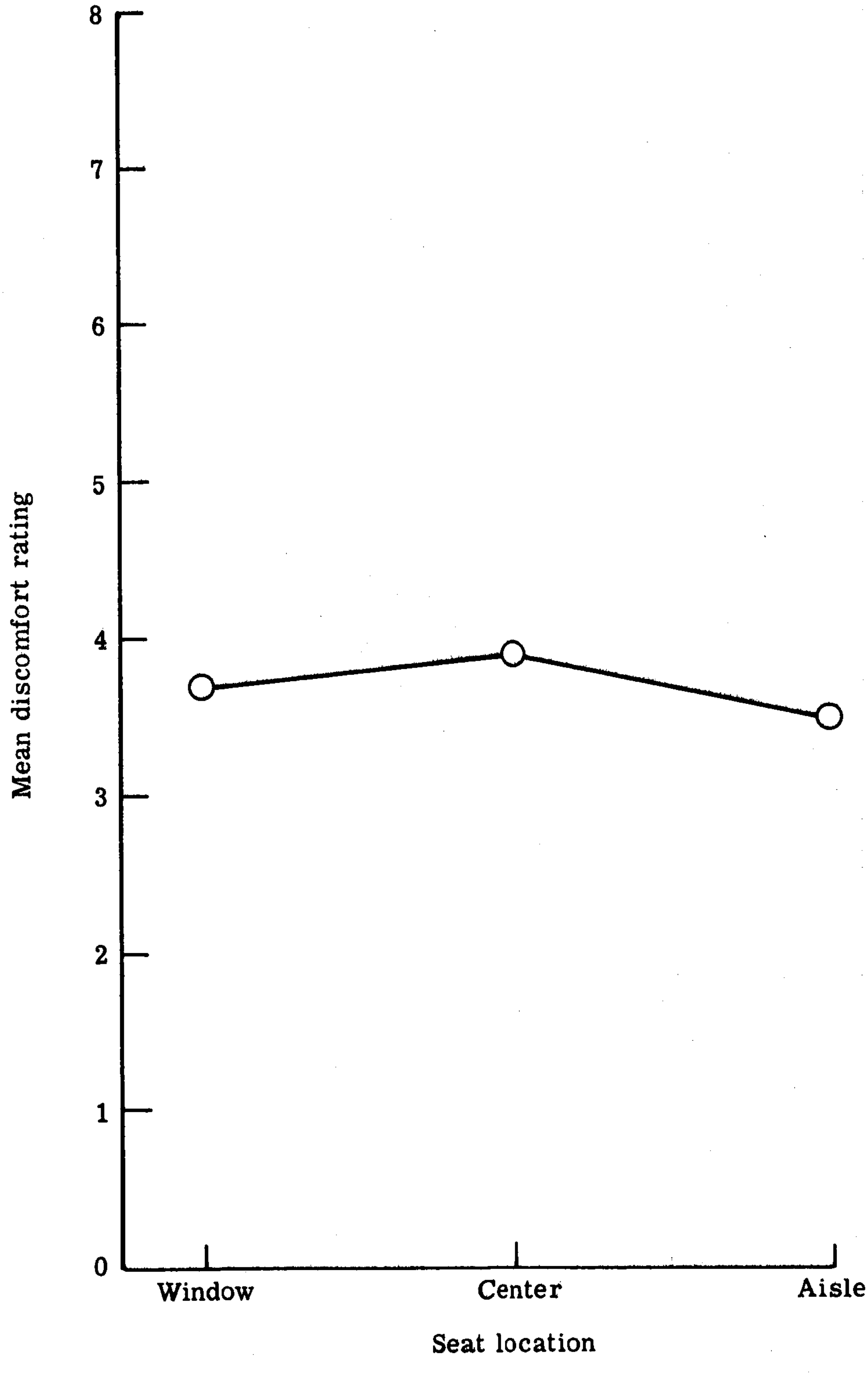


Figure 4.- Overall effect of seat location on mean discomfort rating.

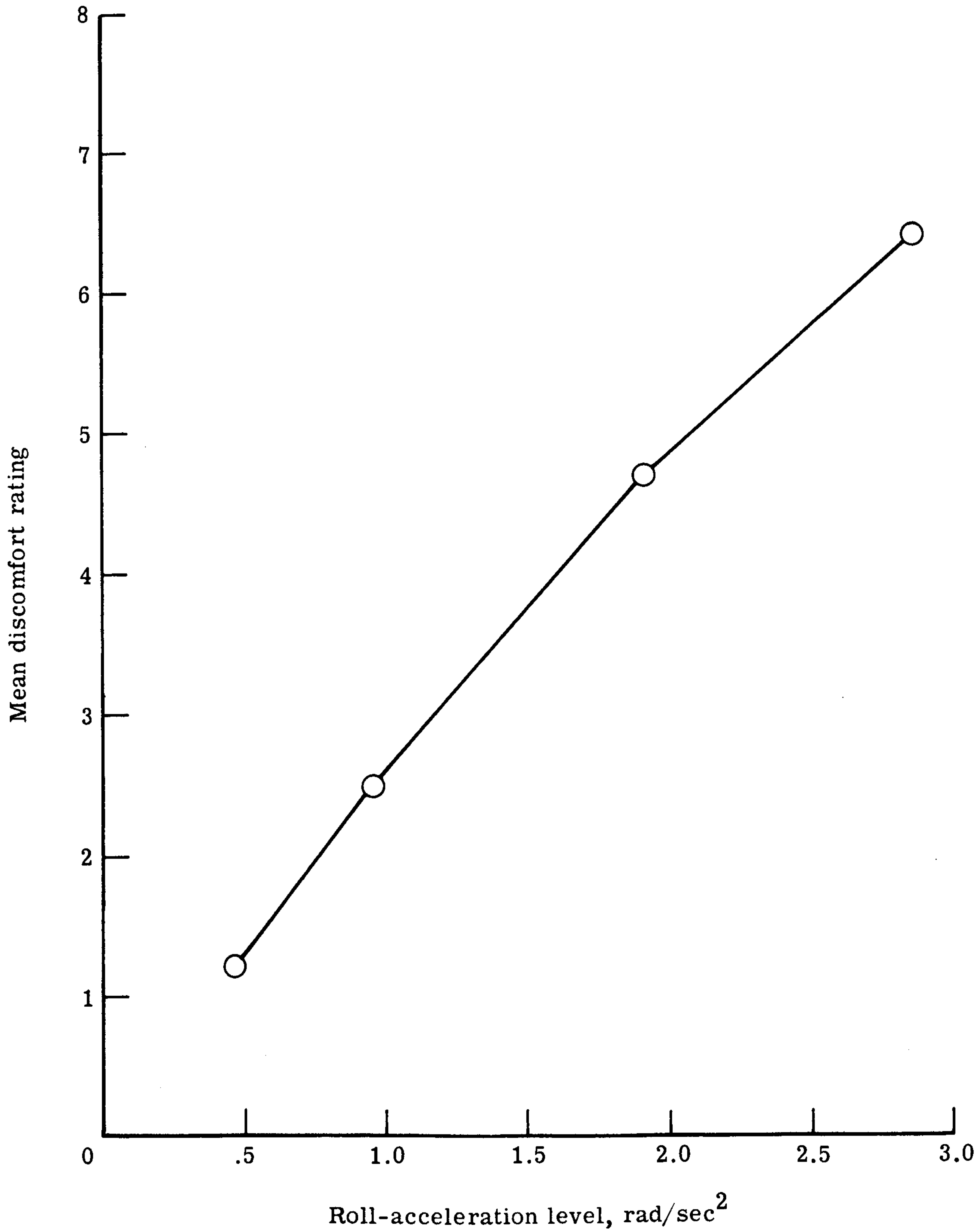


Figure 5.- Overall effect of roll-acceleration level on mean discomfort rating.

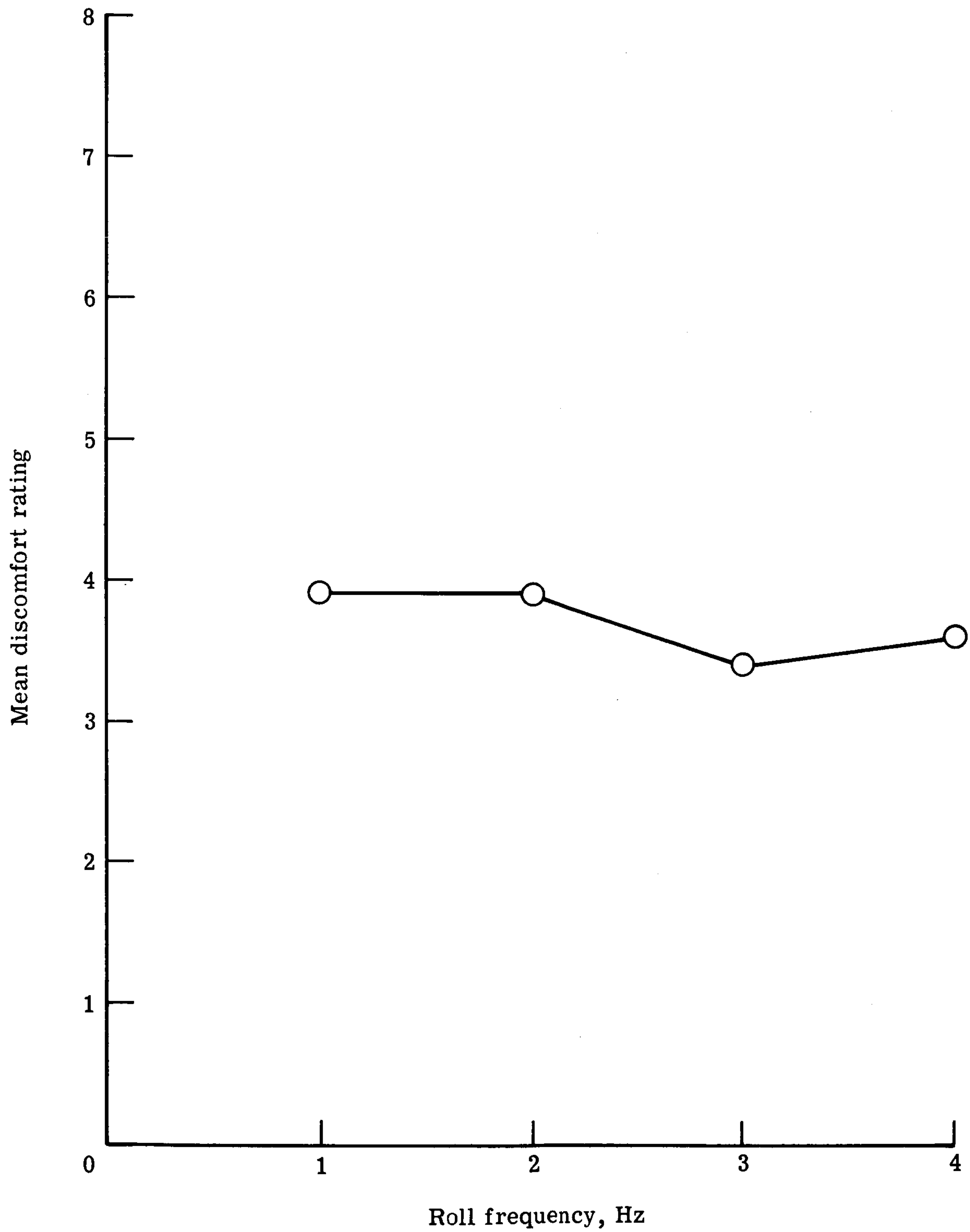


Figure 6.- Overall effect of roll frequency on mean discomfort rating.

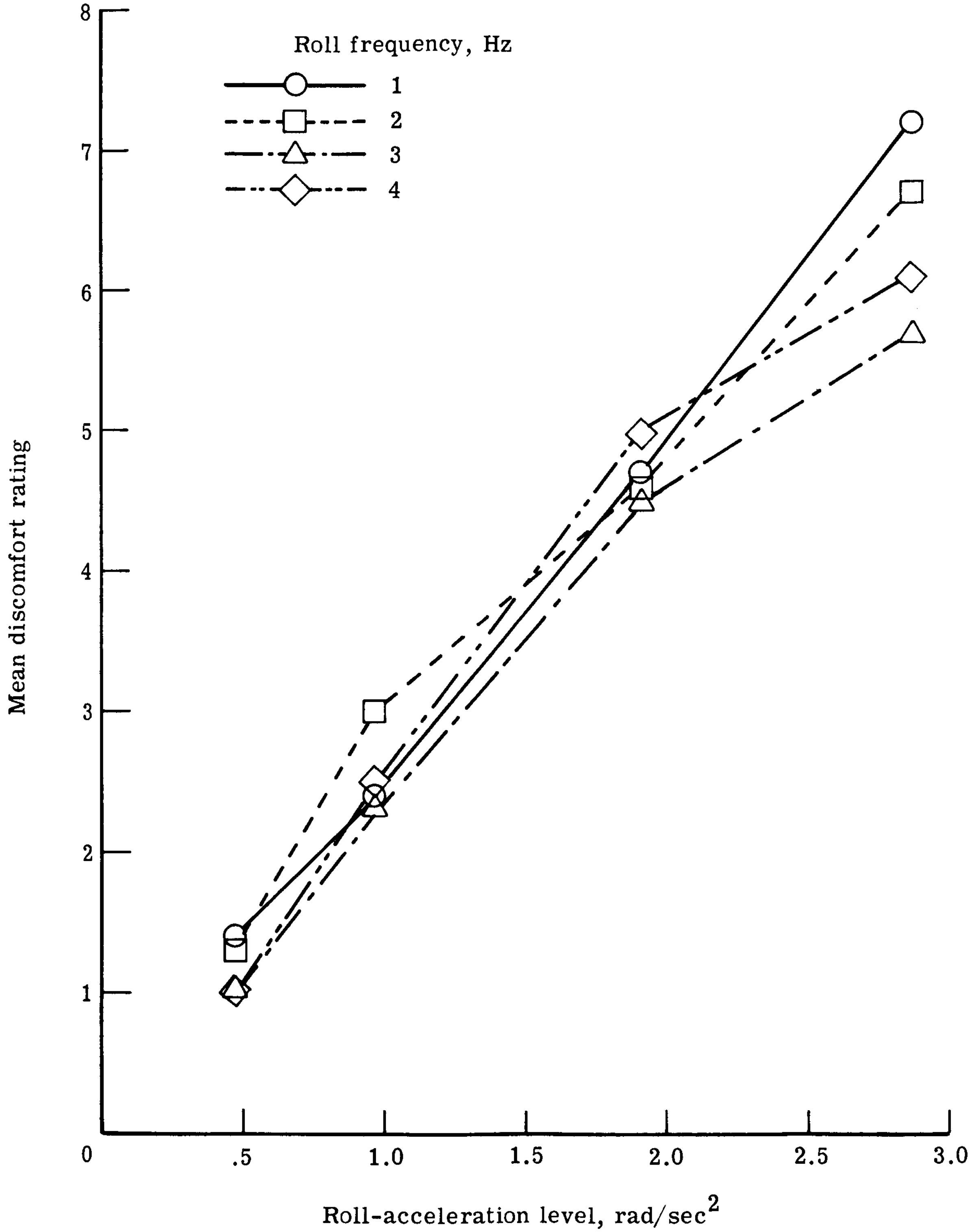


Figure 7.- Interaction between roll-acceleration level and roll frequency.

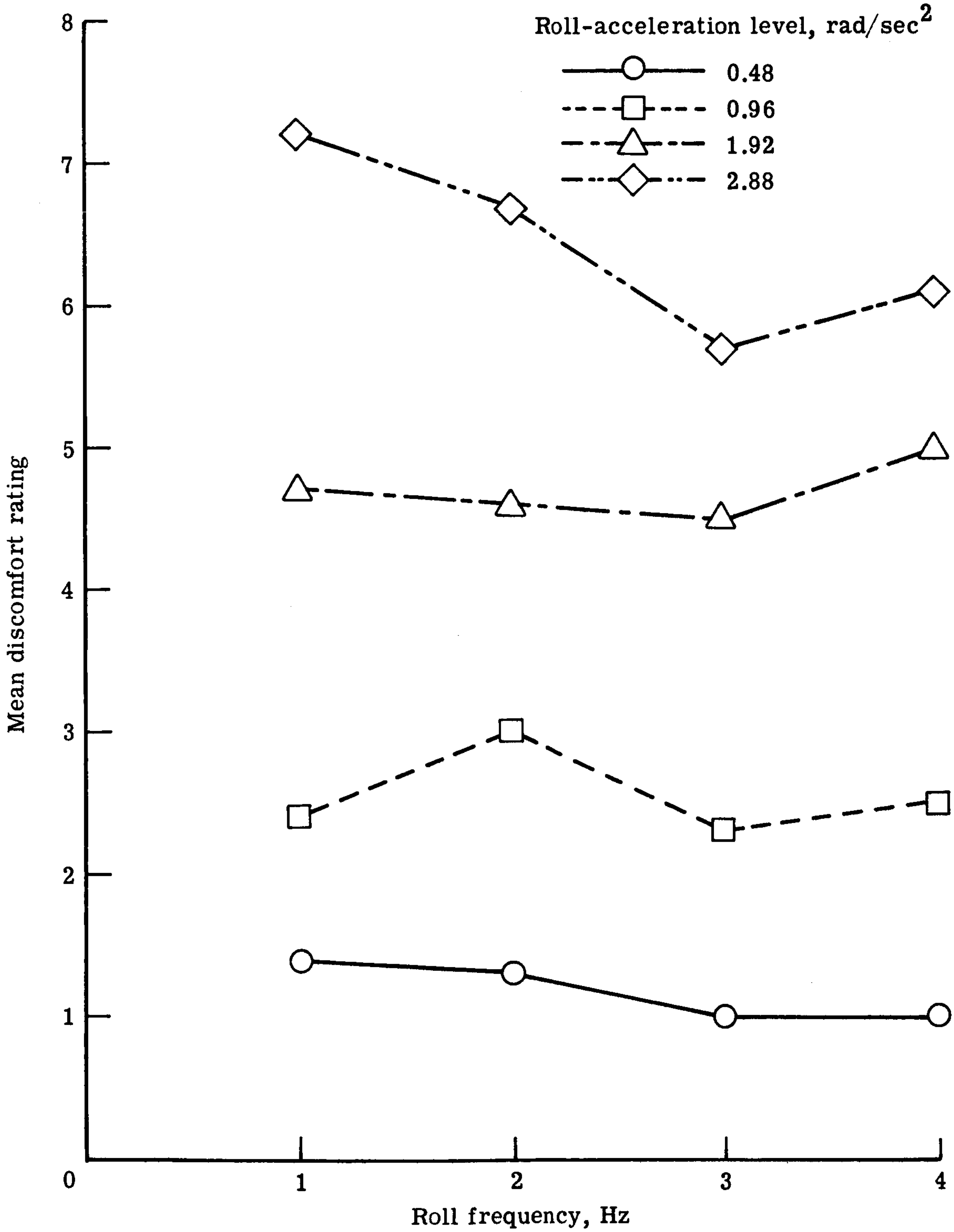


Figure 8.- Mean discomfort rating as a function of roll frequency for each roll-acceleration level.

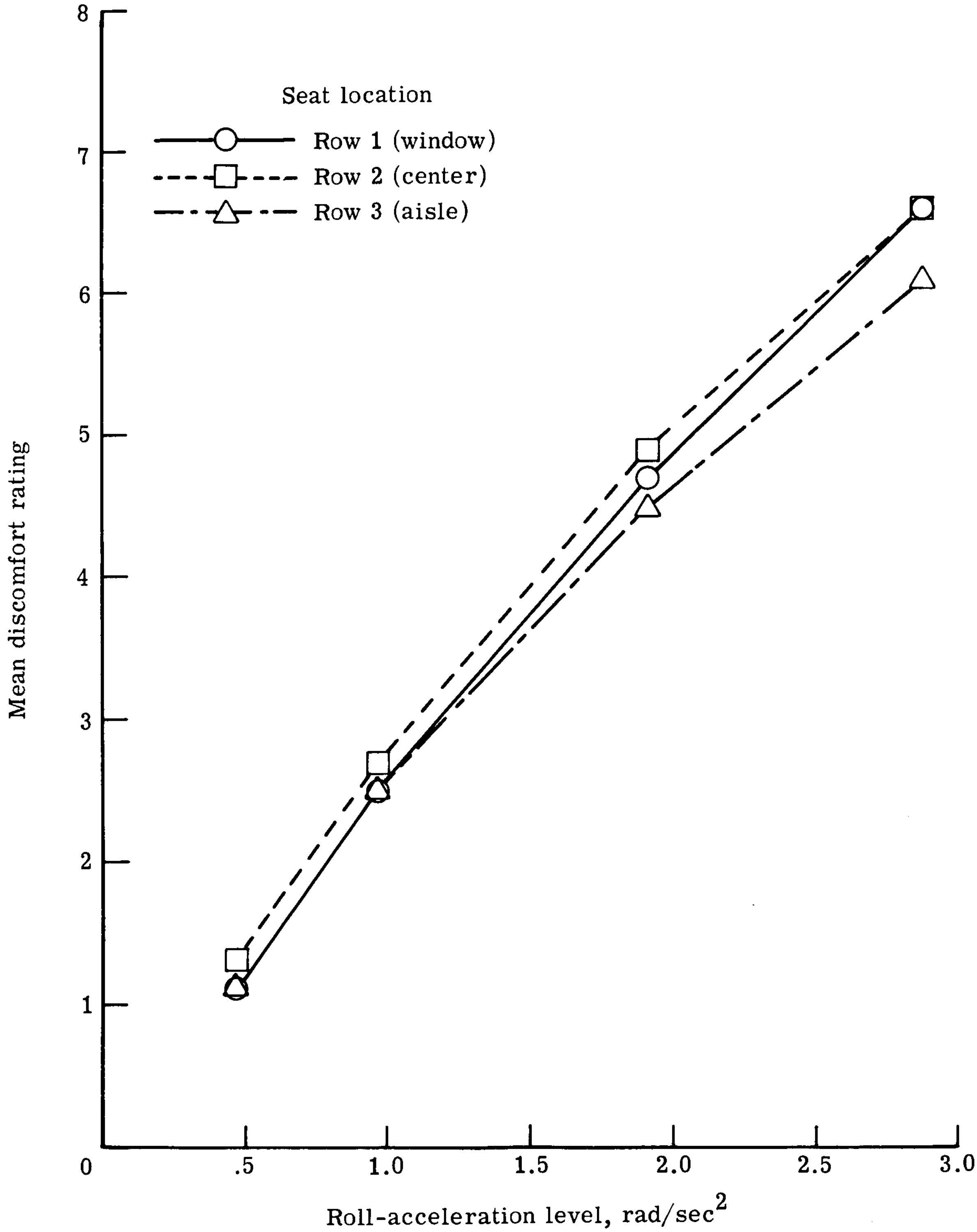


Figure 9.- Mean discomfort rating as a function of roll-acceleration level for each seat location.

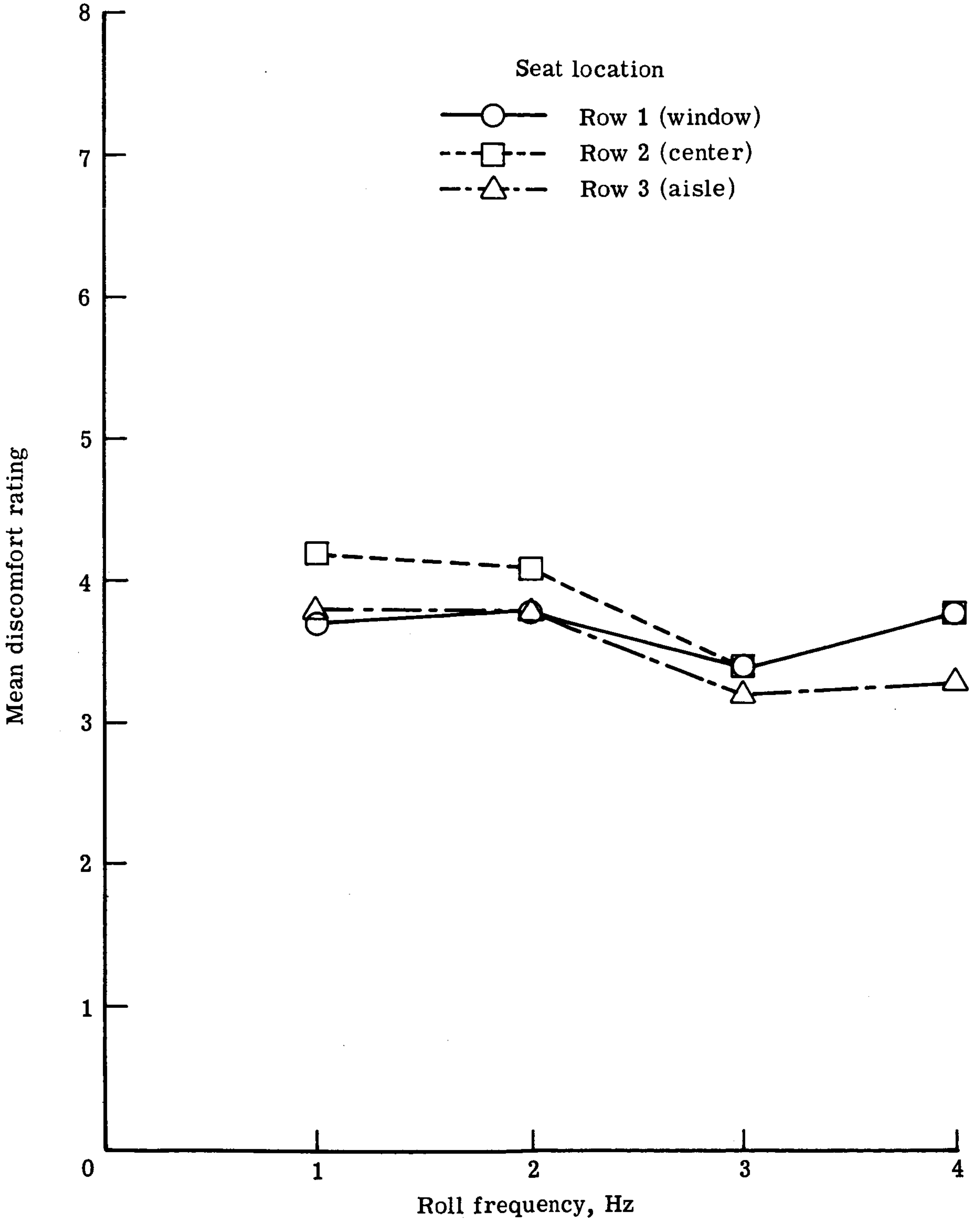


Figure 10.- Mean discomfort rating as a function of roll frequency for each seat location.