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SIMULATOR STUDIES AND PSYCHOPHYSICAL RIDE COMFORT MODELS

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INTRODUCTION

An elementary psychophysical model to predict ride comfort was developed using flight and simulator data where subjects were exposed to six degrees of freedom. This model is presented in references 1 and 2. The model presumes that the comfort response is proportional to the logarithm of the stimulus above some threshold stimulus. The model further presumes that in a condition of multiple motion stimuli, the ride comfort response is dominantly influenced by the maximum effective stimulus existing and only somewhat modified by the existence of other motion stimuli.

In order to verify this concept of comfort modeling, it was necessary to obtain ride comfort data for single degree of freedom random motions and for combinations of random motions. Accordingly, a simulator program was performed at the NASA Langley Research Center to measure subjective comfort response ratings using one degree of freedom, two degrees of freedom, three degrees of freedom, and six degrees of freedom. Some of the data obtained are presented in references 3, 4, 5, and 6. This paper presents an analysis of the single degree of freedom and two degrees of freedom data. Preliminary models of ride comfort response for single degree of freedom random motions and for certain combinations of two degrees of freedom random motions are developed.

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SYMBOLS

$\bar{a}_i$ Rms linear acceleration, g's

$\bar{a}_x$ Rms longitudinal acceleration, g's

$\bar{a}_y$ Rms transverse acceleration, g's

$\bar{a}_z$ Rms vertical acceleration, g's

$\bar{a}_{i_T}$ Threshold to random linear accelerations, g's

$\bar{a}_{x_T}$ Threshold to random longitudinal accelerations, g's

$\bar{a}_{y_T}$ Threshold to random transverse accelerations, g's

$\bar{a}_{z_T}$	Threshold to random vertical accelerations, g's
$\bar{a}_{max}$	Maximum rms linear acceleration, g's
$\bar{a}_{min}$	Minimum rms linear acceleration, g's
$\bar{a}_{max_T}$	Threshold to maximum linear accelerations, g's
$\bar{a}_{TOT}$	Resultant rms linear acceleration, g's
$\bar{a}_{TOT_T}$	Threshold to resultant rms linear acceleration's, g's
$\bar{\omega}_i$	Rms angular velocity, deg/sec
$\bar{\omega}_p$	Rms rolling velocity, deg/sec
$\bar{\omega}_q$	Rms pitching velocity, deg/sec
$\bar{\omega}_r$	Rms yawing velocity, deg/sec
$\bar{\omega}_{i_T}$	Threshold to random angular velocities, deg/sec
$\bar{\omega}_{p_T}$	Threshold to random rolling velocities, deg/sec
$\bar{\omega}_{q_T}$	Threshold to random pitching velocities, deg/sec
$\bar{\omega}_{r_T}$	Threshold to random yawing velocities, deg/sec
$\bar{\omega}_{max}$	Maximum rms angular velocity, deg/sec
$\bar{\omega}_{min}$	Minimum rms angular velocity, deg/sec
$\bar{\omega}_{max_T}$	Threshold to maximum angular velocities, deg/sec
K_i	Motion sensitivity coefficient
K_x	Longitudinal motion sensitivity coefficient
K_y	Transverse motion sensitivity coefficient
K_z	Vertical motion sensitivity coefficient
K_p	Rolling motion sensitivity coefficient
K_q	Pitching motion sensitivity coefficient
K_r	Yawing motion sensitivity coefficient
K_{max}	Sensitivity to maximum rms linear acceleration, or to maximum rms angular velocity
K_{TOT}	Sensitivity to resultant rms linear acceleration

$\bar{S}_i$ Effective stimulus, $\left(\frac{\bar{a}_i}{\bar{a}_{i_T}}\right)^{K_i}$ or $\left(\frac{\bar{\omega}_i}{\bar{\omega}_{i_T}}\right)^{K_i}$

$\bar{S}_{max}$ Maximum effective stimulus

$\bar{S}_{min}$ Minimum effective stimulus

ϕ $= \sin^{-1}\left(\frac{\bar{a}_z}{\sqrt{\bar{a}_z^{\,2} + \bar{a}_y^{\,2}}}\right)$

θ $= \sin^{-1}\left(\frac{\bar{a}_z}{\sqrt{\bar{a}_z^{\,2} + \bar{a}_x^{\,2}}}\right)$

R_S Subjective ride comfort response rating

σ_{R_S} Standard deviation of subjective ride comfort response rating

R_{C_1} Calculated ride comfort response rating to random motions in one degree of freedom

R_{C_2} Calculated ride comfort response rating to random motions in two degrees of freedom

TESTS AND TEST CONDITIONS

The program was planned to expose ten subjects to each of several conditions in single degree and multiple degrees of freedom random motions on the Langley Visual-Motion Simulator. The various conditions for any motion component included variations in the magnitude of the rms motion stimulus and variations in the power spectral shape of the motion stimulus. The spectra were varied between 0 and 2 Hz to represent variations of power spectra measured in flight. A discussion of these conditions is made in references 3 to 6. The various segments of "flight" performed on the simulator and presented in this paper were randomly distributed in 10 simulator "flights" each flown five times. Each "flight" was 36 minutes in length and included 24 separate segments having different conditions as noted above. Two subjects rode each "flight." The subjects were supplied generally by Hampton Institute and represented a wide demographic profile (see references 3 to 6).

The subjects responded to each motion segment by rating the ride comfort on a seven-statement scale consisting of the following ratings:

1. Very comfortable;
2. Comfortable;
3. Somewhat comfortable;
4. Acceptable;
5. Somewhat uncomfortable;
6. Uncomfortable;
7. Very uncomfortable.

For correlation with past psychophysical model development and for the analysis of this paper, this seven-statement scale was folded into a five-point scale ranging from 1 for very comfortable to 5 for very uncomfortable.

The actual motions experienced by the subjects were measured by a set of three linear accelerometers and three angular rate gyros installed in the simulator. The subjective ride comfort response ratings are related to these measured motions in this paper.

The Langley Visual-Motion Simulator used in these experiments is shown in figure 1. The simulator is driven by six hydraulic legs which are controlled by a computer. The input signals were on a digital tape and therefore repeatable. Because the simulator is a dynamic system, it is subjected to changes in friction, pressure, etc., and therefore does not precisely duplicate a motion for an identical input signal (see references 3 to 6). For analysis purposes averages of the measured motion components for a given segment were used.

The interior of the Langley Visual-Motion Simulator is shown in figure 2. The subjects rode in the pilot's and co-pilot's seats and the instruments and controls were inoperative.

RESULTS AND DISCUSSION

The subjective ride comfort response ratings presented and analyzed in this paper are the mean values for the ten subjects that experienced each segment. The psychophysical models developed herein were designed to fit the mean subjective ratings and not the total mass of data. The relationships presented are therefore between the models and the mean subjective ratings.

Single Degree of Freedom Responses

The subjective ride comfort response ratings for the single degree of freedom motion tests are plotted as a function of the logarithms of the various stimuli in figures 3 to 8. The standard deviations of the subject ratings are also shown. The vertical, transverse, longitudinal, pitching, rolling and yawing stimuli are shown on figures 3, 4, 5, 6, 7 and 8, respectively.

The mean subjective ride comfort response ratings were fitted with a model of the following format for the linear acceleration degrees of freedom,

$$R_{C_1} = 1 + K_i \log_{10} \left(\frac{\bar{a}_i}{\bar{a}_{i_T}}\right)$$

and for the angular degrees of freedom,

$$R_{C_1} = 1 + K_i \log_{10} \left(\frac{\bar{\omega}_i}{\bar{\omega}_{i_T}}\right) .$$

The threshold stimulus and the constants so established are presented on table I. The thresholds for the linear acceleration stimuli range from 0.00512 to 0.0075 g's. These values are based on the assumption that a ride comfort response rating of very comfortable represents a condition where the stimuli is not sensed essentially or is not considered of any significance. These levels are for rms values of random oscillatory accelerations and are about twice as large as thresholds to constant linear accelerations. The thresholds for rms random angular stimuli range from 0.3 to 0.87 degrees per second. Values for constant angular velocities range from 0.5 to 2.0 degrees per second.

The constants, K_i, represent effectively the ride comfort sensitivity to a given motion stimulus. The subjects were much more sensitive to transverse accelerations than to vertical or longitudinal accelerations. In like manner the subjects were more sensitive to rolling motions than to pitching and yawing motions. These results indicate that from the standpoint of ride comfort, humans are more disturbed by motions whose vectors do not lie in the median plane of the body than by those that do.

On table II are listed the correlation coefficients of the mean subjective ratings and the ratings calculated by the models just discussed. Very good correlation is indicated. The standard deviations of the model ratings fror the mean subjective ratings are also shown on table II and are appreciably smaller than the standard deviations of the subjective ratings from their mean values.

Two Degrees of Freedom Responses

It was the intent for the two degree of freedom experiments to combine two of the single degree of freedom tests just discussed. It was not possible, however,to do this precisely because of the nature of the simulator. On tables III through VII are listed the single degree of freedcm results intended to be combined and the actual results experienced when the inputs to the simulator were combined. The subjective ride comfort response ratings and their standard deviations are also shown on tables III to VII. The two motions combined on each table are as follows:

Vertical and Transverse	Table III
Vertical and Longitudinal	Table IV
Rolling and Yawing	Table V
Vertical and Pitching	Table VI
Transverse and Rolling	Table VII.

Although not always true, the resultant components of motion in the combined motion experiments were larger than their corresponding individual components in the single degree of freedom tests.

Model Development for Combinations of Like Stimuli

In modeling for combinations of two linear acceleration stimuli, an assumption was made that the response would be to the resultant acceleration and not to its separate components. The most sensitive sensor of the body for sensing linear acceleration is the otolith element of the inner ear which responds basically to the total acceleration vector (reference 7). The otolith organ as a single sensor responds to all components of linear acceleration. Accordingly, the model for combining two linear accelerations has the following format:

$$R_{C_2} = 1 + K_{TOT} \log_{10} \left(\frac{\bar{a}_{TOT}}{\bar{a}_{TOT_T}}\right)$$

where $\bar{a}_{TOT}$ is the vector sum of the two applied components of acceleration and $\bar{a}_{TOT_T}$ is the threshold for accelerations parallel to $\bar{a}_{TOT}$. As the sensitivities and thresholds varied for the separate components of linear accelerations previously discussed, the threshold and sensitivity for combined motions would vary depending on the orientation of the resultant acceleration vector.

For combining vertical and transverse accelerations the following was used:

$$\bar{a}_{TOT_T} = \bar{a}_{y_T} + (0.00059) \sin \phi$$

and

$$K_{TOT} = K_y - (0.775) \sin \phi$$

where

$$\sin \phi = \frac{\bar{a}_z}{\sqrt{\bar{a}_z^{\,2} + \bar{a}_y^{\,2}}}$$

For combining vertical and longitudinal accelerations the following was used:

$$\bar{a}_{TOT_T} = \bar{a}_{x_T} + (0.00238) \sin \theta$$

and

$$K_{TOT} = K_x - (0.147) \sin \theta$$

where

$$\sin \theta = \frac{\bar{a}_z}{\sqrt{\bar{a}_z^{\,2} + \bar{a}_x^{\,2}}}$$

These models are presented as isocontours of ride comfort response rating on a vertical and transverse acceleration grid and on a vertical and longitudinal acceleration grid on figures 9 and 10, respectively. Also shown are the mean subjective response ratings from table III and table IV, respectively. The models show that the sensitivity to the motion varies rapidly as the total acceleration vector rotates from the transverse axis or the longitudinal axis such that larger components of transverse or longitudinal acceleration are more readily tolerated when combined with vertical acceleration. Also shown on figure 9 are isocontours from reference 8 obtained from flight data. The agreement is not startling but it must be remembered that limited data exist and that the phenomenon of ride comfort is one where the standard deviation of the subjective data is of the order of 3/4 of a rating point on a five-point scale.

The rolling and yawing motions are also like stimuli. The most sensitive organs for sensing angular motions are the semi-circular canals. A semi-circular canal measures only that vector component of angular motion perpendicular to the plane of the canal. Each canal has separate sensors and neural pathways and therefore unlike the otolith organ does not measure the resultant vector but its components. It was assumed then that a model based on the resultant angular velocity vector would not be appropriate. A model was therefore developed assuming that the maximum effective stimulus dominated the response rating and that the other component only modified this dominant influence. The model so developed is as follows:

$$R_{C_2} = 1 + \log_{10} (\bar{S}_{max}) - 1.365 \left(\frac{\log_{10} (\bar{S}_{min})}{\log_{10} (\bar{S}_{max})}\right)$$

where

$$\bar{S}_i = \left(\frac{\bar{a}_i}{\bar{a}_{i_T}}\right)^{K_i}$$

Isocontours of response rating on a grid of rolling and yawing angular velocities are shown on figure 11. The data from table V are also shown on figure 11. The negative coefficient in this model represents a synergistic influence of yawing velocity on responses to rolling velocity. Much larger rolling velocities are tolerable when combined with yawing velocity than when not. The data obtained are all in the roll dominant area of figure 11. The model presented may not apply for yaw-dominant conditions.

Model Development for Combinations of Unlike Stimuli

In modeling combinations of unlike stimuli, it is recognized that both the otolith organs and semi-circular canals are involved and are the most sensitive sensors involved. With separate sensors and separate neural pathways it was again assumed that a model responding dominantly to the maximum effective stimulus and being only modified by the second component would be appropriate.

The model so developed for combinations of vertical and pitching motions is as follows:

$$R_{C_2} = 1 + \log_{10} (\bar{S}_{max}) - 0.0112 \left(\frac{\log_{10} (\bar{S}_{min})}{\log_{10} (\bar{S}_{max})}\right)$$

and for combinations of transverse and rolling motions is

$$R_{C_2} = 1 + \log_{10} (\bar{S}_{max}) - 0.1534 \left(\frac{\log_{10} (\bar{S}_{min})}{\log_{10} (\bar{S}_{max})}\right)$$

where

$$\bar{S}_{max} = \left(\frac{\bar{a}_{max}}{\bar{a}_{max_T}}\right)^{K_{max}}$$

or

$$= \left(\frac{\bar{\omega}_{max}}{\bar{\omega}_{max_T}}\right)^{K_{max}}$$

Isocontours of response rating on a grid of vertical and pitching motions are presented on figure 12 and for transverse and rolling motions on figure 13. The data from tables VI and VII are also shown on figures 12 and 13, respectively.

The data on figure 13 are primarily in the pitch-dominant area and the model may not apply in the vertical-dominant area. The model indicates very little influence of vertical motions on the comfort response to pitching motions.

The data on figure 13 are primarily in the transverse-dominant region and the model may not apply in the roll-dominant region. The model shows a slightly synergistic effect of rolling velocity on responses to transverse acceleration.

The relationship between the mean subjective response ratings and the ratings calculated by the various models for combined two degrees of freedom motions are shown in table VIII. The correlation coefficients show relatively good agreement but not nearly as good as those previously discussed for the single degree of freedom models. The standard deviations also are somewhat larger for these combined motions than for the single degree of freedom motions previously discussed. The standard deviations of the subjective response rating from the mean subjective response ratings are, however, somewhat smaller than for the single degree of freedom results. These results imply that additional study of the interactive effects of combined motions will be necessary for improved insight to the problems involved and the characteristics of the models required.

CONCLUDING REMARKS

Subjective ride comfort responses to single degree and two degrees of freedom random motions have been examined. Models with responses proportional to the logarithm of the stimuli are proposed for single degree of freedom motion responses. The data and the models developed for single degree of freedom random motions indicate that the subjects were much more sensitive to random transverse accelerations and rolling velocities than to the other degrees of freedom. For combinations of linear accelerations, a model based on the resultant acceleration is proposed.

For other motion combinations, models based on the concept of a primary response to the dominant stimulus with small modifications from the other stimulus are proposed. Fair correlation exists between the models and the mean subjective ride comfort response ratings. The data and models suggest a synergistic effect of certain motion combinations; for example, the presence of yawing motions for the conditions studied causes greater tolerance to rolling motions.

REFERENCES

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8. Jacobson, Ira D.; and Richards, Larry G.: Ride Quality Evaluation II: Modelling of Airline Passenger Comfort. (Mem. Rep. 403217, Univ. of Virginia; NASA Grant NGR 47-005-181.) To be published in Ergonomics, vol. 18, 1975.

Table I.- An Elementary Psychophysical Model for Ride Comfort Responses to Single Degree of Freedom Random Motions

Motion Stimulus, $\bar{a}_i$ or $\bar{\omega}_i$	K_i	Threshold Stimulus, $\bar{a}_{i_T}$ or $\bar{\omega}_{i_T}$
$\bar{a}_z$	2.370	0.00750
$\bar{a}_y$	3.145	0.00691
$\bar{a}_x$	2.517	0.00512
$\bar{\omega}_p$	3.756	0.8740
$\bar{\omega}_q$	2.573	0.3025
$\bar{\omega}_r$	2.679	0.7240

Table II.- The Relation of the Mean Subjective Response Ratings with Calculated Ratings for Single Degree of Freedom Random Motions

Motion Stimulus	Correlation Coefficient	Rms-Standard Deviation	Average Rms-Standard Deviation of Subjective Ratings from Mean Subjective Ratings
$\bar{a}_z$	0.978	0.151	0.747
$\bar{a}_y$	0.977	0.235	0.690
$\bar{a}_x$	0.945	0.286	0.610
$\bar{\omega}_p$	0.948	0.316	0.715
$\bar{\omega}_q$	0.939	0.440	0.708
$\bar{\omega}_r$	0.976	0.216	0.663

Table III.- Ride Comfort Responses to Combined Random Vertical and Transverse Motions

$\bar{a}_y$	$\bar{a}_z$	R_S	σ_{R_S}	$\bar{a}_y$	$\bar{a}_z$	R_S	σ_{R_S}
			Single Degree of Freedom Tests				
0	0.0870	3.500	0.624	0	0.0890	3.950	0.864
0	0.0573	3.000	1.106	0	0.0597	2.900	0.615
0	0.0306	2.200	0.753	0	0.0303	2.500	0.745
0.0608	0	3.500	0.527	0.0612	0	4.000	0.782
			Two Degrees of Freedom Tests				
0.0628	0.0846	4.000	0.577	0.0611	0.0849	3.700	0.258
0.0810	0.0575	3.700	0.746	0.0675	0.0591	4.150	0.784
0.0675	0.0334	3.500	0.333	0.0616	0.0385	3.550	0.725
			Single Degree of Freedom Tests				
0.0857	0	4.450	0.762	0.0890	0	4.450	0.599
0.0608	0	3.500	0.527	0.0612	0	4.000	0.782
0.0330	0	3.250	0.830	0.0341	0	3.100	0.532
0	0.0573	3.000		0	0.0597	2.900	
			Two Degrees of Freedom Tests				
0.0873	0.0575	4.400	0.658	0.0831	0.0607	4.200	0.587
0.0810	0.0575	3.700	0.746	0.0675	0.0591	4.150	0.783
0.0532	0.0634	4.050	0.685	0.0417	0.0622	2.500	0.707
			Single Degree of Freedom Tests				
0.0890	0	4.450	0.599	0.0857	0	4.450	0.762
0.0612	0	4.000	0.782	0.0608	0	3.500	0.527
0.0341	0	3.100	0.532	0.0330	0	3.250	0.830
0	0.0573	3.000		0	0.0597	2.900	
			Two Degrees of Freedom Tests				
0.0845	0.0538	4.350	0.747	0.0920	0.0625	4.100	0.994
0.0649	0.0650	4.100	0.699	0.0663	0.0602	3.100	0.810
0.0396	0.0617	3.150	0.626	0.0385	0.0561	3.600	0.658

Table IV.- Ride Comfort Responses to Combined Random Vertical and Longitudinal Motions

$\bar{a}_x$	$\bar{a}_z$	R_S	σ_{R_S}
	Single Degree of Freedom Tests		
0	0.0870	3.500	0.624
0	0.0573	3.000	1.106
0	0.0306	2.200	0.753
0.0598	0	3.625	0.232
	Two Degrees of Freedom Tests		
0.0636	0.0819	3.750	0.755
0.0670	0.0583	4.250	0.677
0.0548	0.0331	3.250	0.540
	Single Degree of Freedom Tests		
0.0900	0	4.312	0.753
0.0835	0	4.375	0.694
0.0598	0	3.625	0.232
0.0571	0	3.688	0.372
0.0315	0	2.938	0.496
0.0315	0	2.812	0.259
0	0.0573	3.000	1.106
	Two Degrees of Freedom Tests		
0.1008	0.0609	4.650	0.580
0.0840	0.0627	4.250	0.540
0.0670	0.0583	4.250	0.677
0.0655	0.0686	3.500	0.667
0.0354	0.0644	2.600	0.460
0.0327	0.0546	3.000	0.333

Table V.- Ride Comfort Responses to Combined Random Rolling and Yawing Motions

$\overline{\omega}_p$	$\overline{\omega}_r$	R_S	σ_{R_S}
	Single Degree of Freedom Tests		
6.104	0	4.150	0.852
4.048	0	3.375	0.876
2.254	0	2.500	0.667
0	1.328	1.650	0.699
	Two Degrees of Freedom Tests		
7.577	2.496	4.050	0.725
5.564	2.731	3.600	0.775
4.733	3.231	2.800	0.538
	Single Degree of Freedom Tests		
0	4.758	3.100	0.460
0	4.525	2.950	0.896
0	1.328	1.650	0.669
0	1.247	1.600	0.699
0	1.134	1.550	0.599
0	1.070	1.550	0.497
4.048	0	3.375	0.876
	Two Degrees of Freedom Tests		
8.165	4.052	3.950	0.643
7.516	3.301	3.800	0.949
5.564	2.732	3.600	0.744
5.365	2.591	2.850	0.338
4.906	1.797	2.800	0.350
4.089	1.689	3.350	0.338

Table VI.- Ride Comfort Responses to Combined Random Vertical and Pitching Motions

$\bar{a}_z$	$\bar{\omega}_q$	R_S	σ_{R_S}
	Single Degree of Freedom Tests		
0.0870	0	3.500	0.624
0.0573	0	3.000	1.106
0.0306	0	2.200	0.753
0	2.0614	2.938	0.853
	Two Degrees of Freedom Tests		
0.0948	3.0591	3.700	0.632
0.0762	2.8574	3.100	0.460
0.0563	2.4538	3.050	0.497
	Single Degree of Freedom Tests		
0.0890	0	3.950	0.864
0.0597	0	2.900	0.615
0.0303	0	2.500	0.745
0	2.0152	3.375	0.641
	Two Degrees of Freedom Tests		
0.0812	2.8272	3.250	0.540
0.0700	2.6444	4.100	0.843
0.0568	2.4391	3.350	0.784
	Single Degree of Freedom Tests		
0	3.0766	4.250	0.655
0	2.0614	2.938	0.853
0	1.0703	2.750	0.463
0.0573	0	3.000	1.106
	Two Degrees of Freedom Tests		
0.0892	3.6558	4.000	0.745
0.0762	2.8514	3.100	0.460
0.0720	2.4632	3.750	0.791

Table VII.- Ride Comfort Responses to Combined Random Transverse and Rolling Motions

$\bar{a}_y$	$\bar{\omega}_p$	R_S	σ_{R_S}	$\bar{a}_y$	$\bar{\omega}_p$	R_S	σ_{R}
			Single Degree of Freedom Tests				
0.0857	0	4.450	0.762	0.0890	0	4.450	0.5
0.0608	0	3.500	0.527	0.0612	0	4.000	0.7
0.0330	0	3.250	0.830	0.0341	0	3.100	0.5
0	4.0481	3.375	0.876	0	3.1771	3.438	1.0
			Two Degrees of Freedom Tests				
0.0955	4.2591	4.550	0.599	0.0968	4.3749	4.800	0.4
0.0671	3.1237	3.350	0.416	0.0680	3.9086	4.300	0.6
0.0496	4.4645	3.500	0.408	0.0478	3.9441	3.350	0.4
			Single Degree of Freedom Tests				
0	6.1042	4.150	0.852	0	5.2468	4.200	0.7
0	4.0481	3.375	0.876	0	3.1771	3.438	1.0
0	2.2539	2.500	0.699	0	1.9809	2.750	0.5
0.0608	0	3.500	0.527	0.0612	0	4.000	0.7
			Two Degrees of Freedom Tests				
0.0783	5.9730	4.300	0.483	0.0833	5.9112	4.800	0.4
0.0671	3.1237	3.250	0.416	0.0680	3.9086	4.300	0.6
0.0644	2.8152	3.900	0.658	0.0559	3.0566	3.250	0.4

Table VIII.- The Relation of the Mean Subjective Response Ratings with Calculated Ratings for Two Degrees of Freedom Random Motions

Motion Stimulus	Correlation Coefficient	Rms-Standard Deviation	Average Rms-Standard Deviation of Subjective Ratings from Mean Subjective Ratings
$\bar{a}_z$ and $\bar{a}_y$	0.614	0.325	0.674
$\bar{a}_z$ and $\bar{a}_x$	0.860	0.458	0.569
$\bar{\omega}_p$ and $\bar{\omega}_r$	0.791	0.304	0.582
$\bar{a}_z$ and $\bar{\omega}_q$	0.631	0.390	0.628
$\bar{a}_y$ and $\bar{\omega}_p$	0.716	0.384	0.537

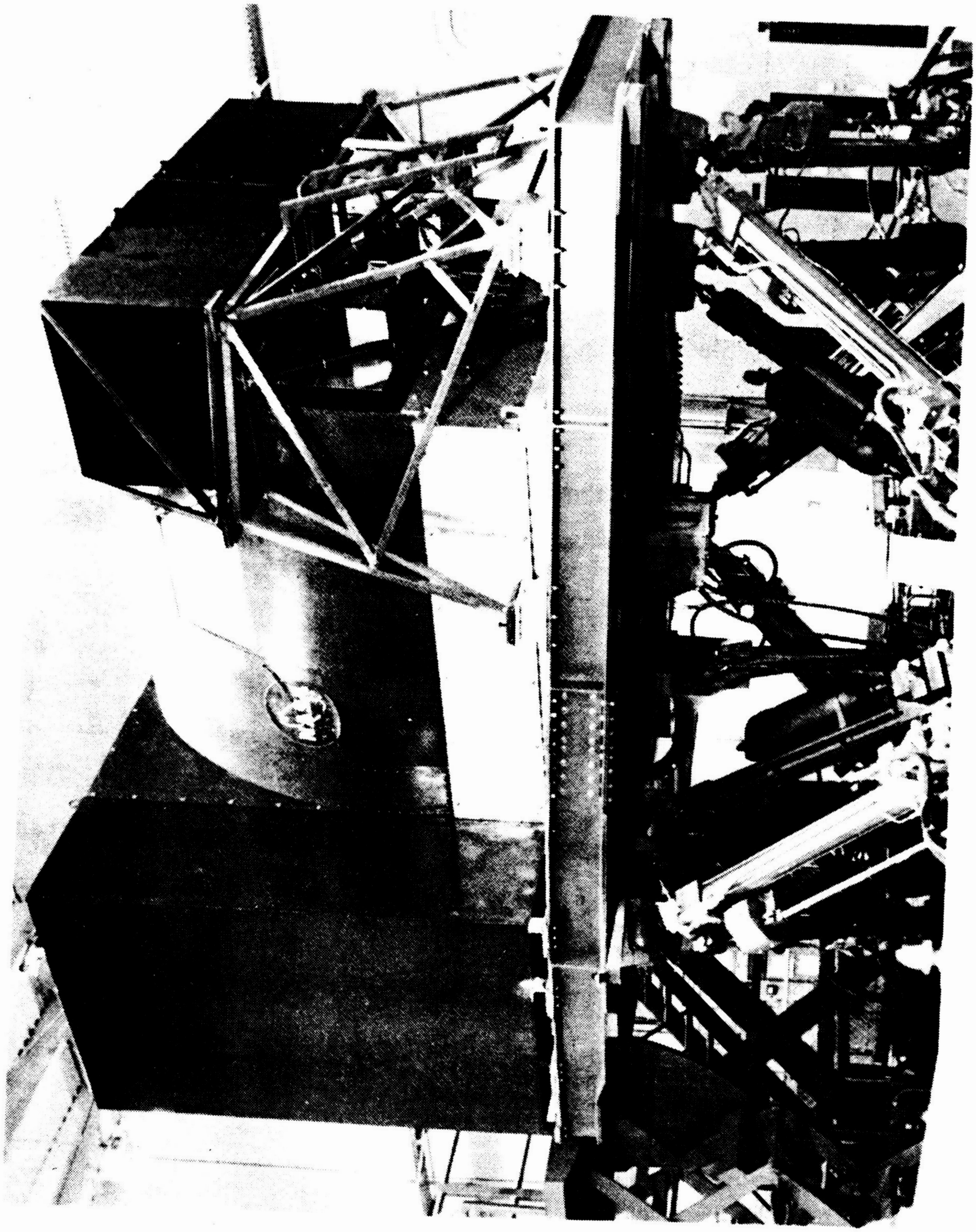

Figure 1.- NASA Langley visual-motion simulator.

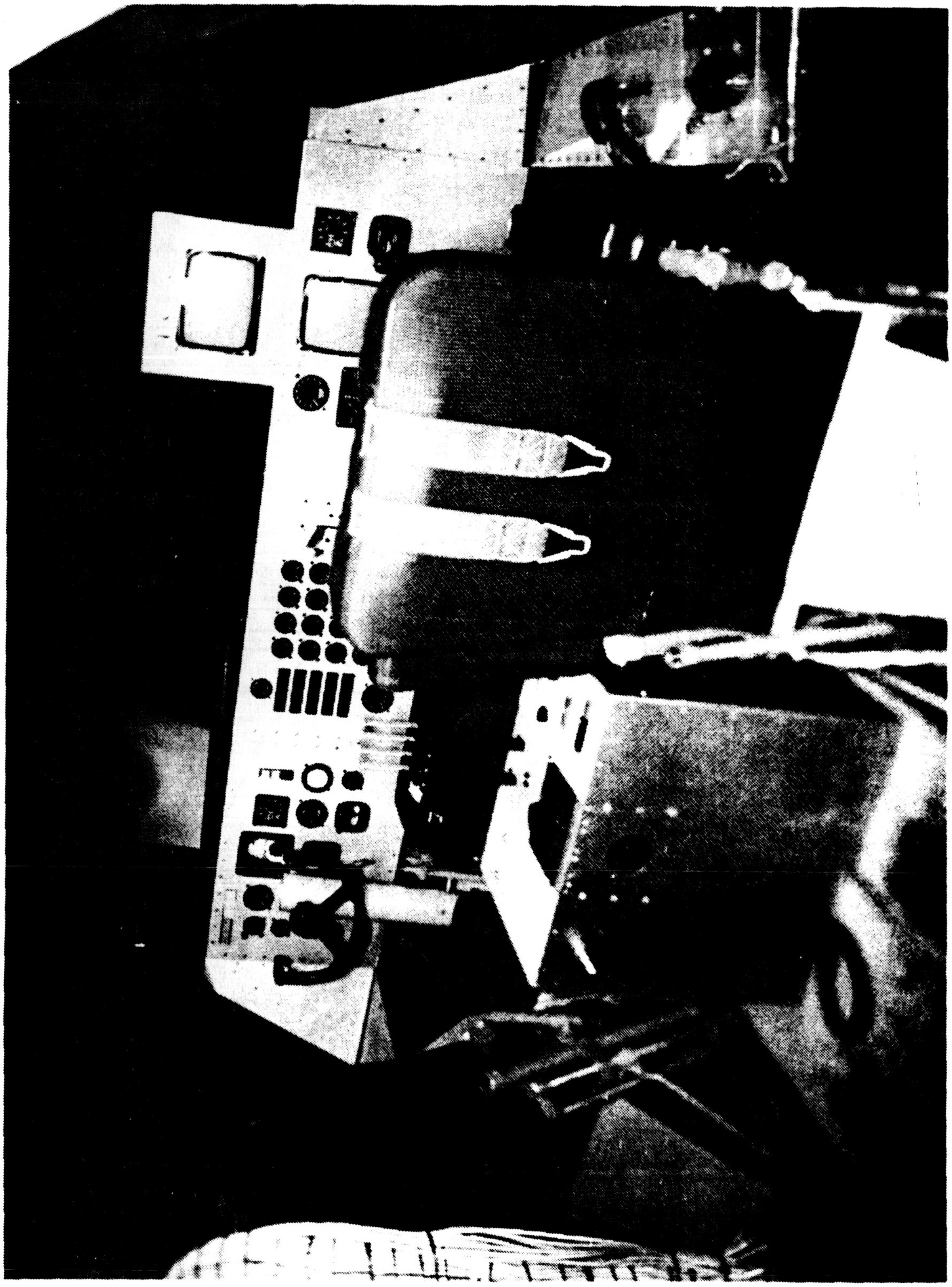

Figure 2.- Interior of the NASA Langley visual-motion simulator.

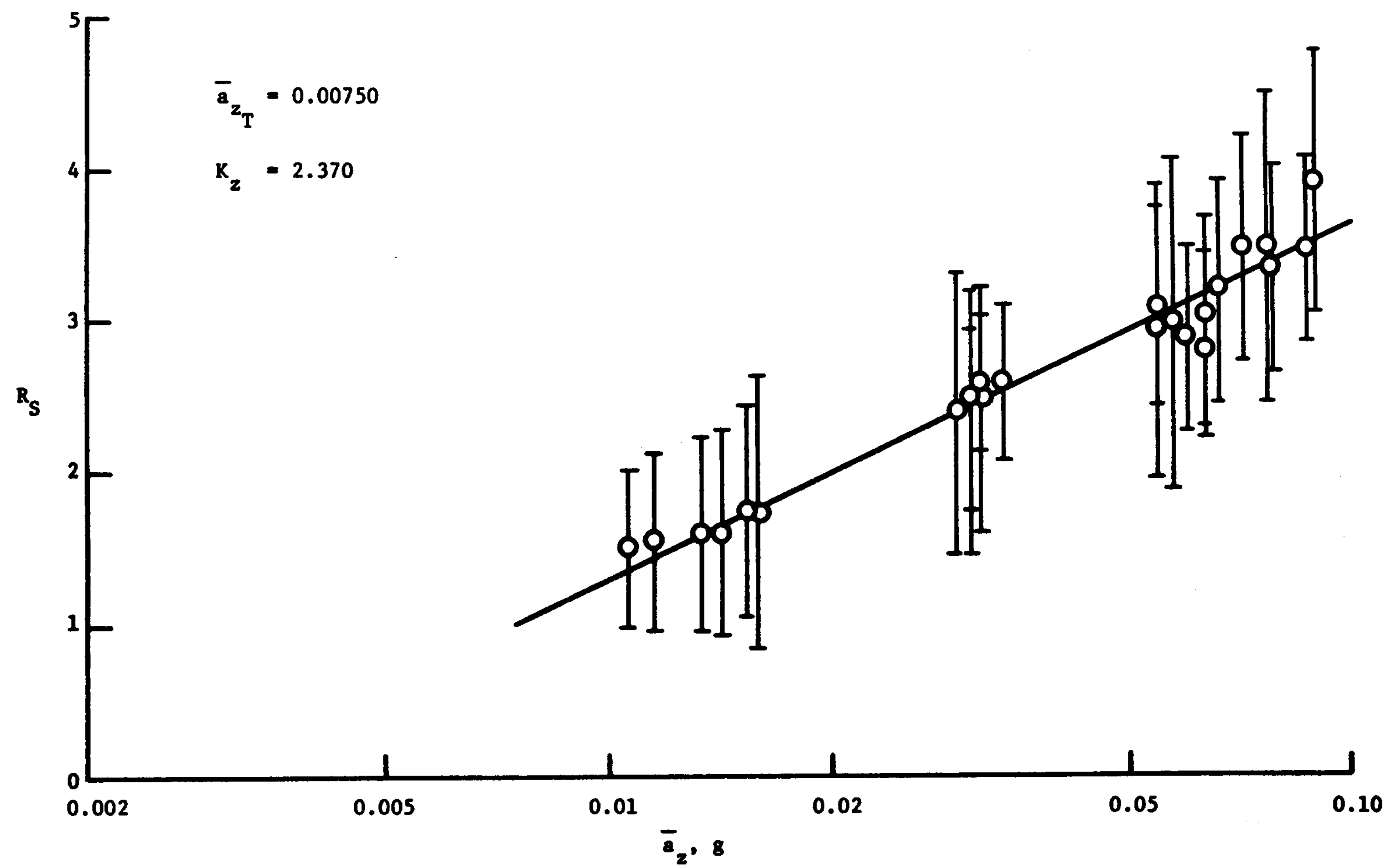

Figure 3.- Variation of ride comfort response rating with rms vertical accelerations.

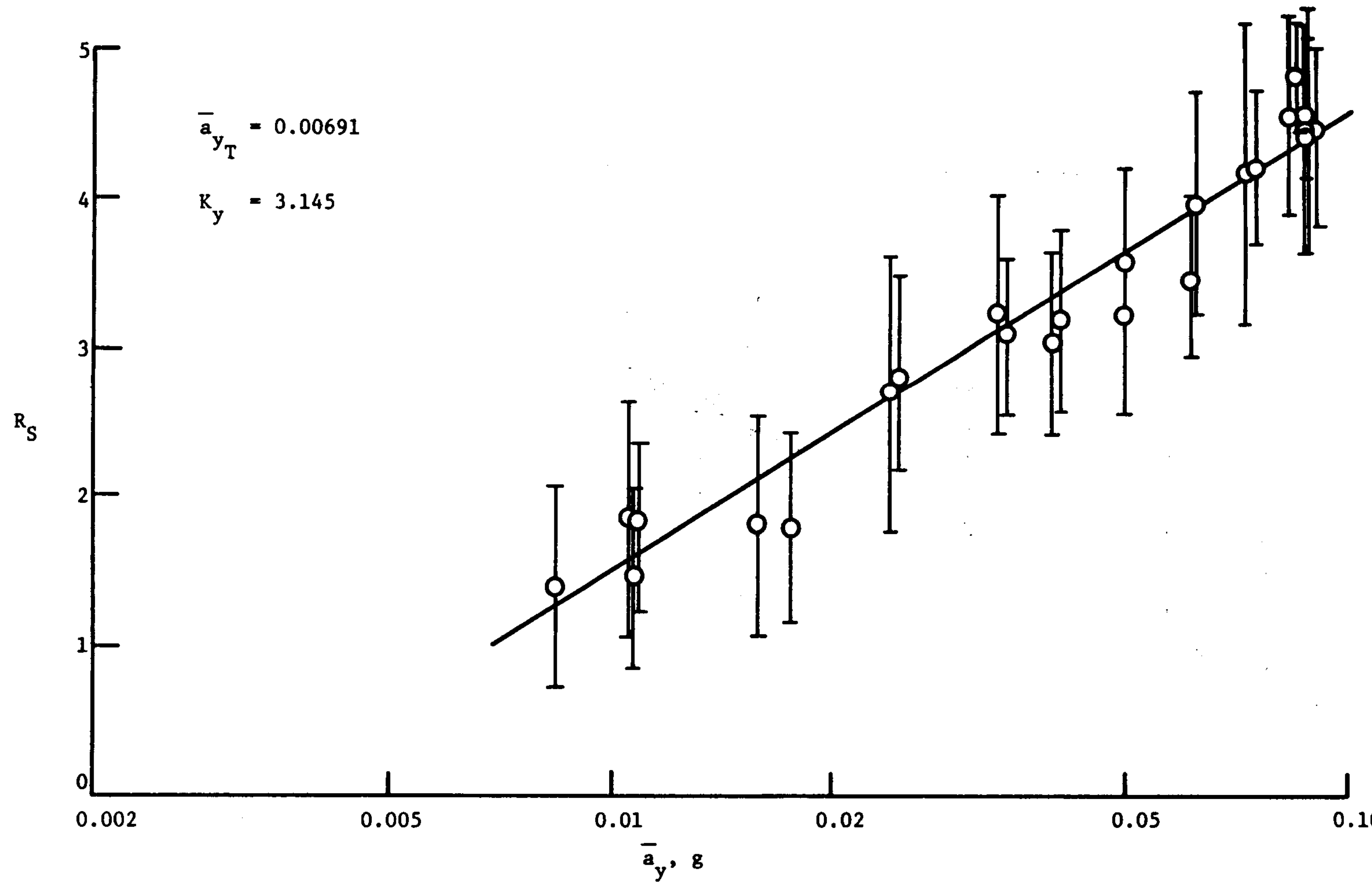

Figure 4.- Variation of ride comfort response rating with rms transverse accelerations.

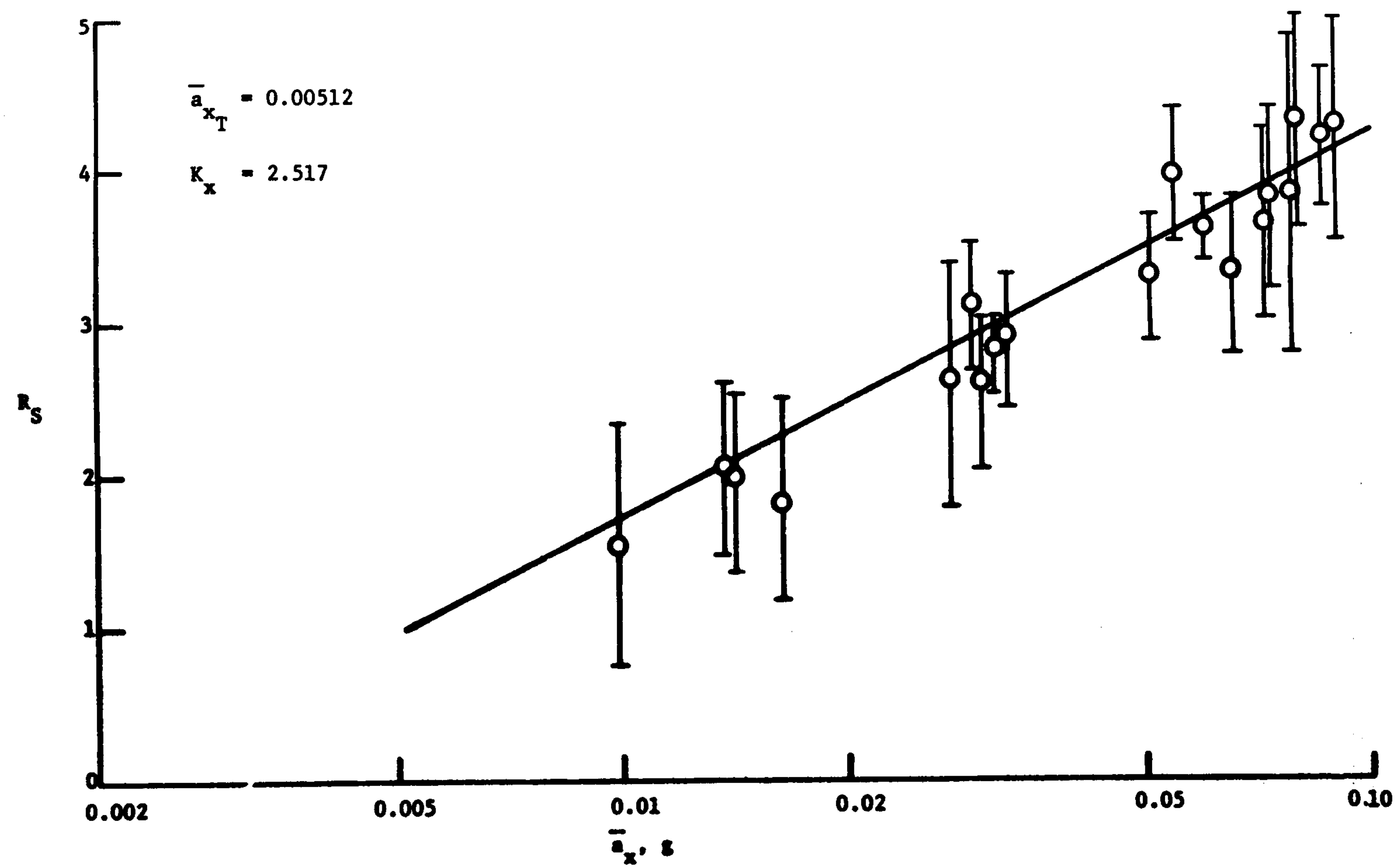

Figure 5.- Variation of ride comfort response rating with rms longitudinal accelerations

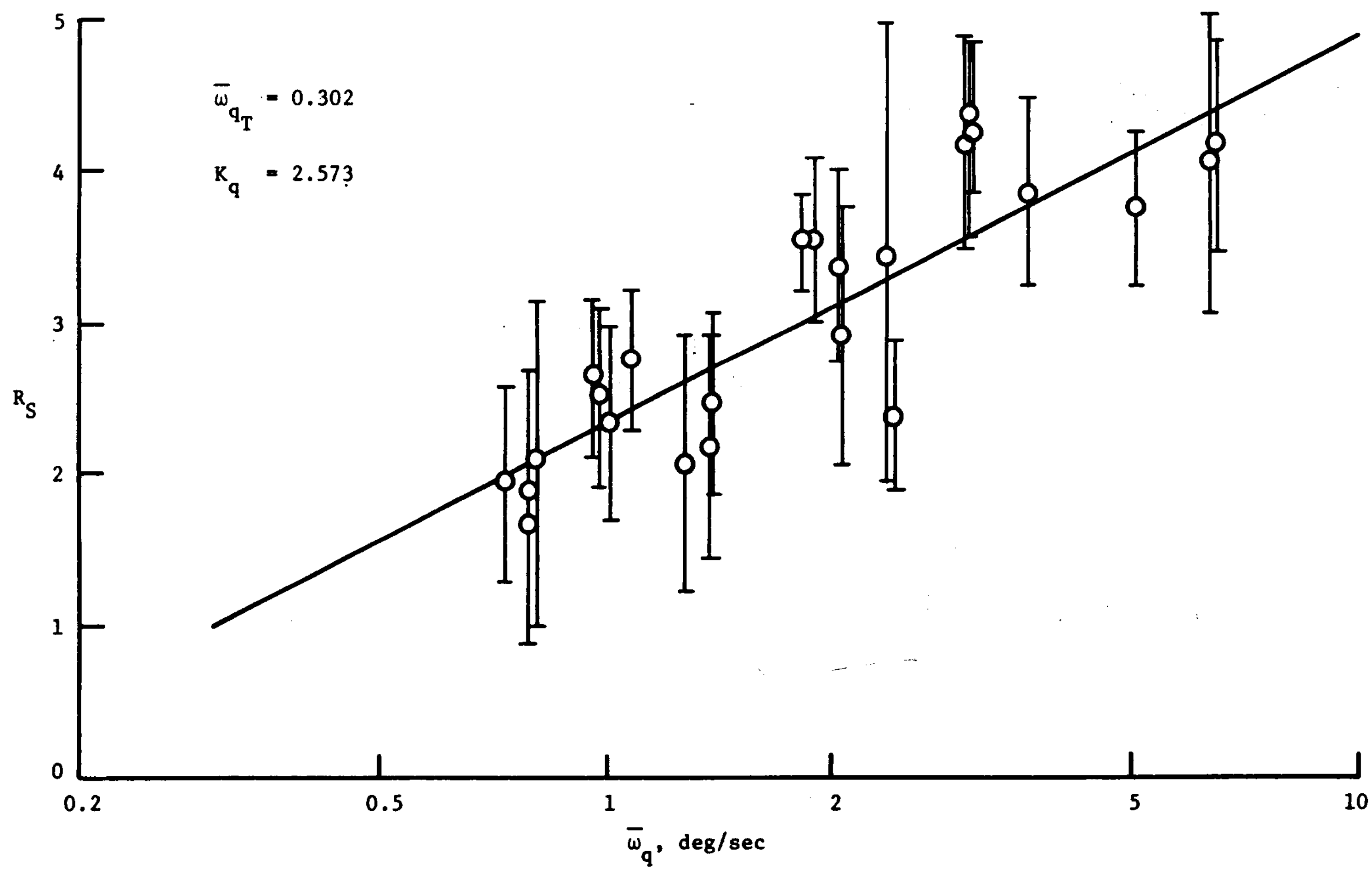

Figure 6.- Variation of ride comfort response rating with rms pitching velocity.

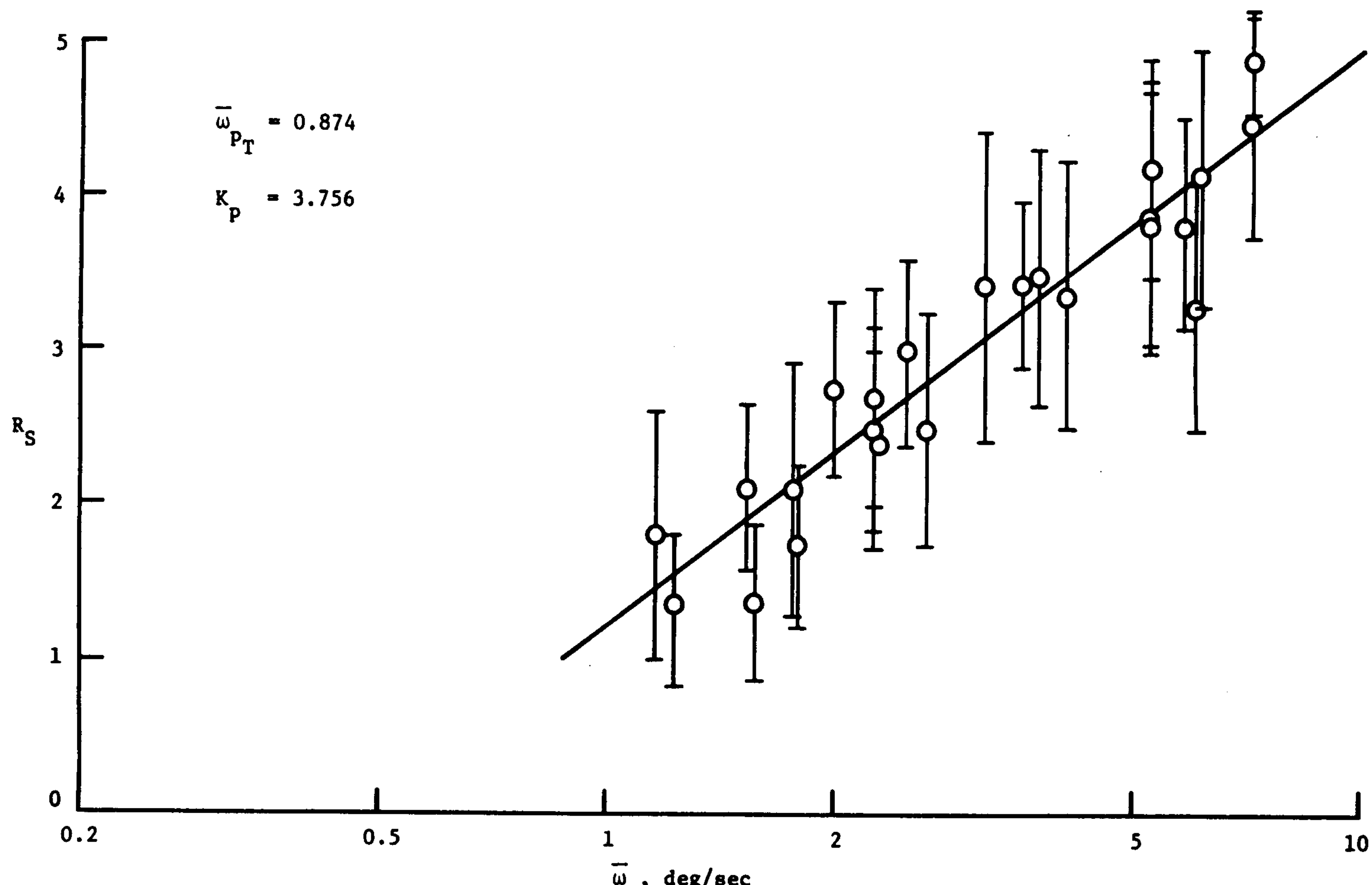

Figure 7.- Variation of ride comfort response rating

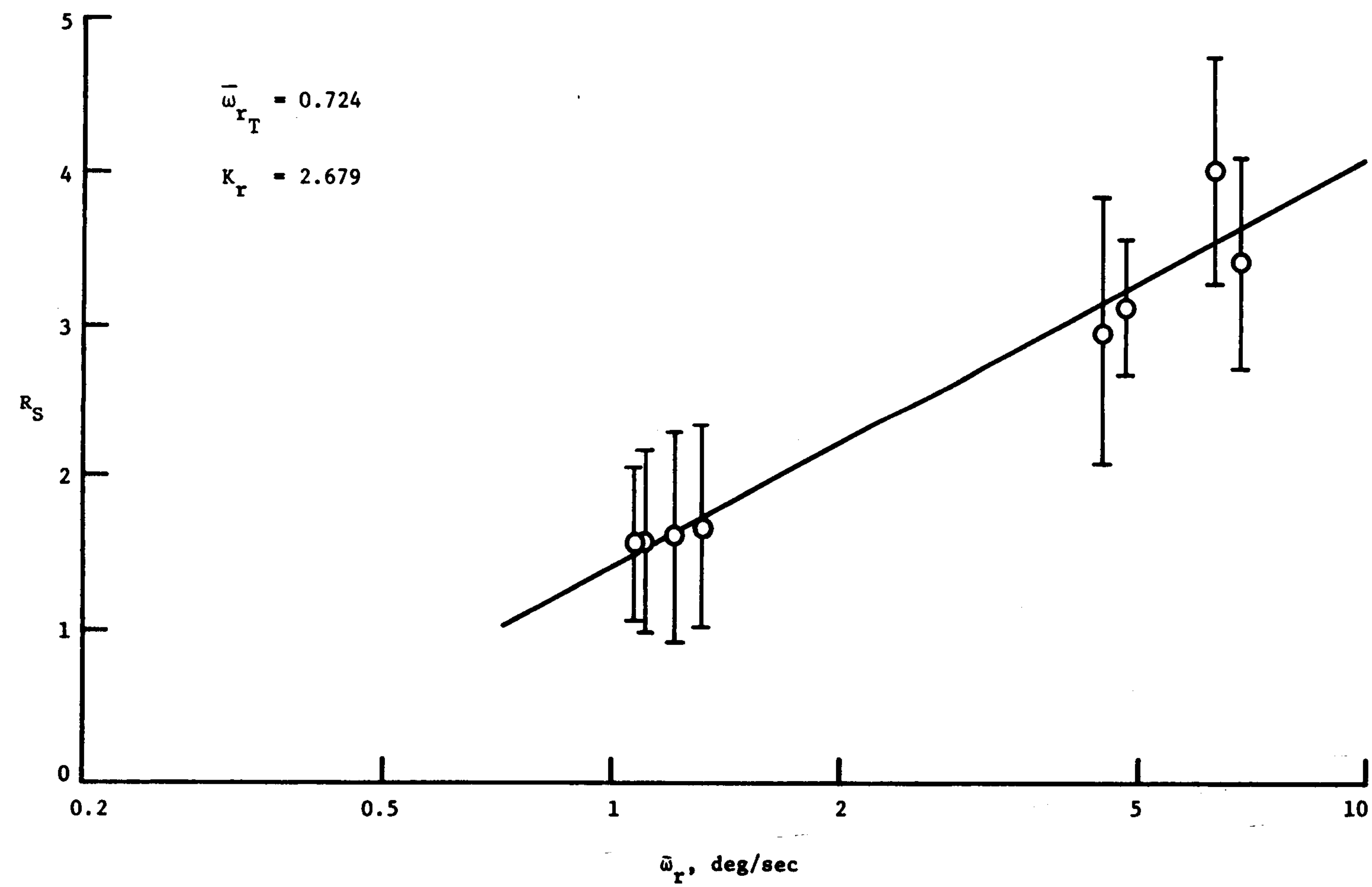

Figure 8.- Variation of ride comfort response rating with rms yawing velocity.

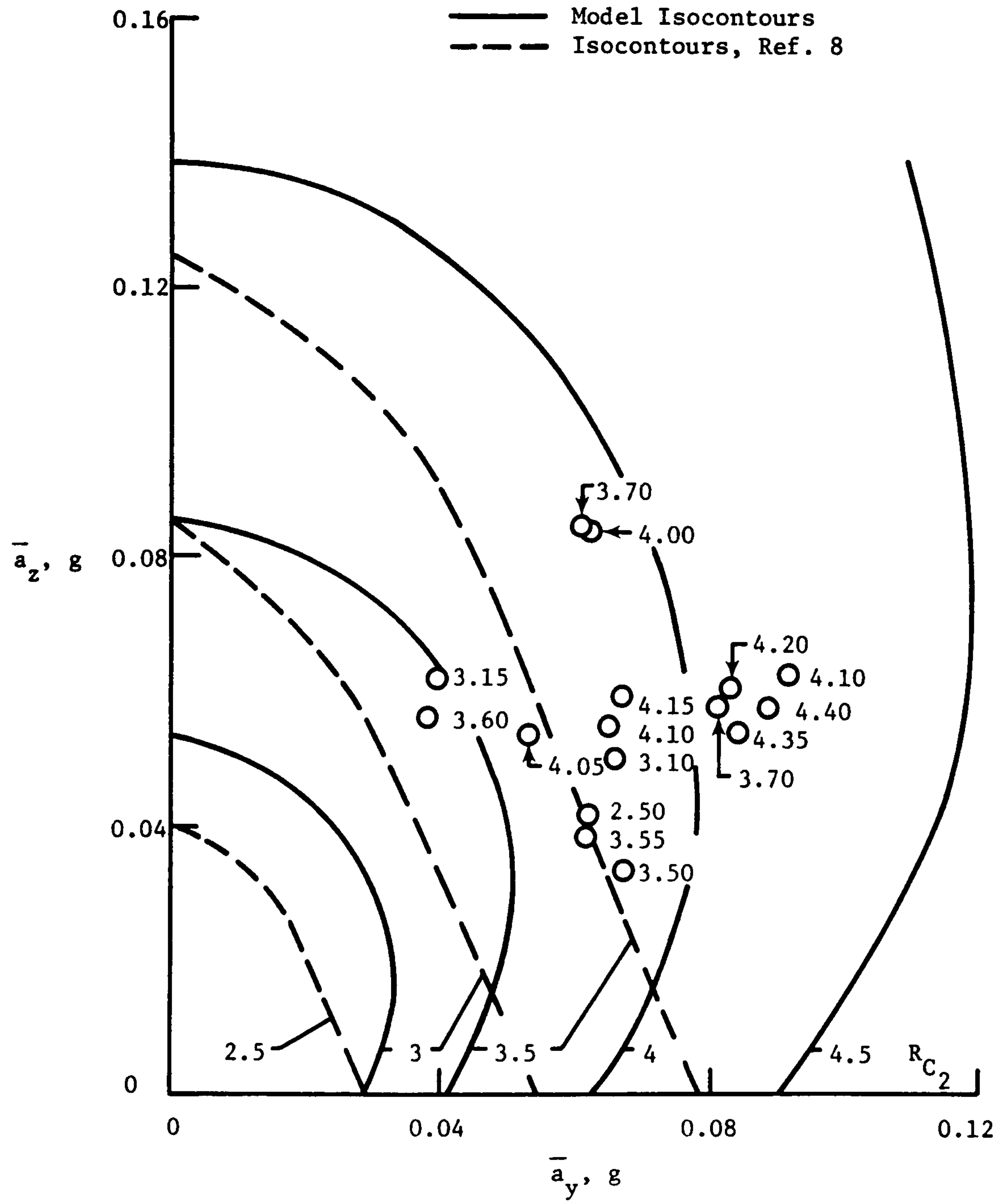

Figure 9.- Ride comfort responses to combined random vertical and transverse motions.

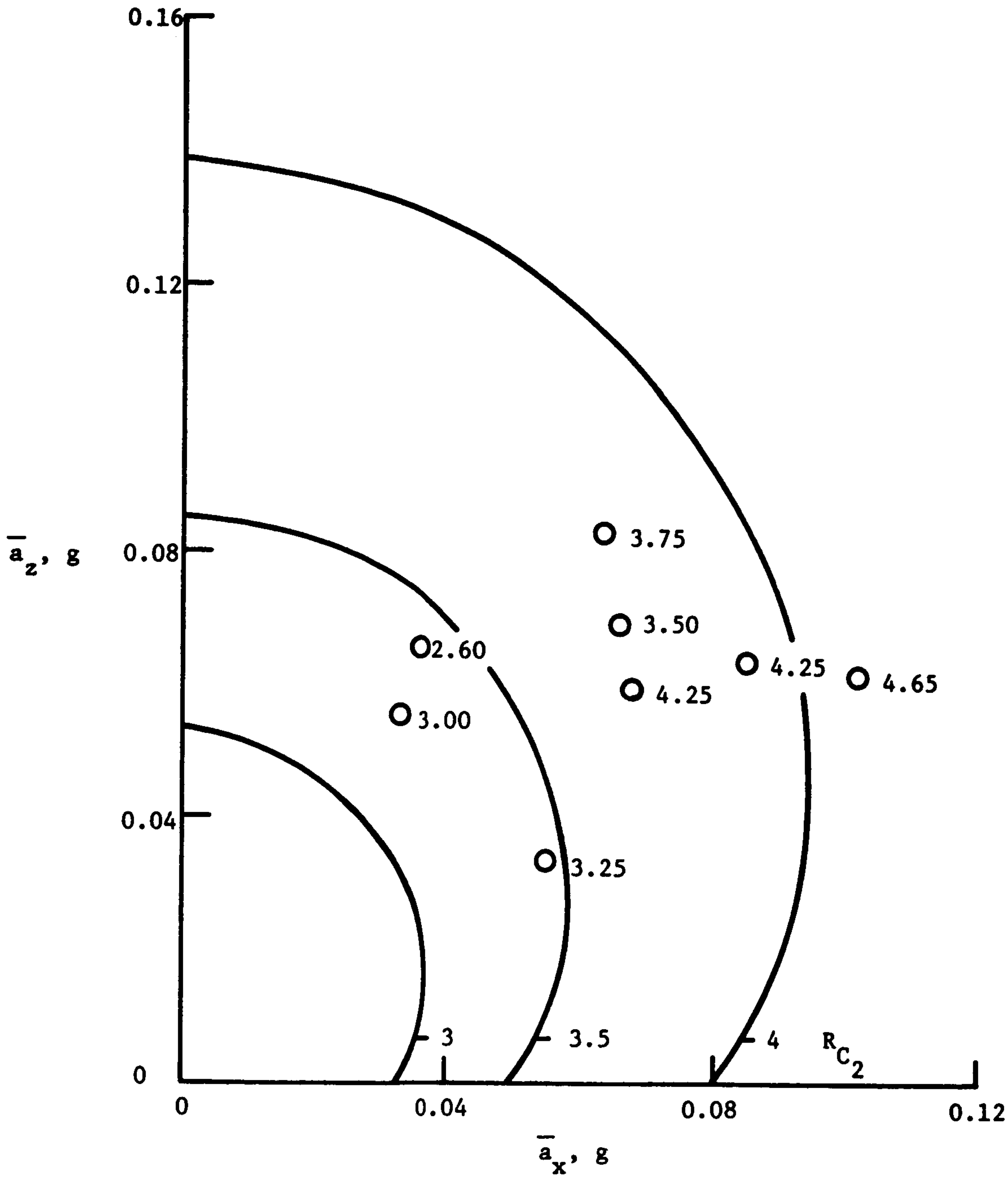

Figure 10.- Ride comfort responses to combined random vertical and longitudinal motions.

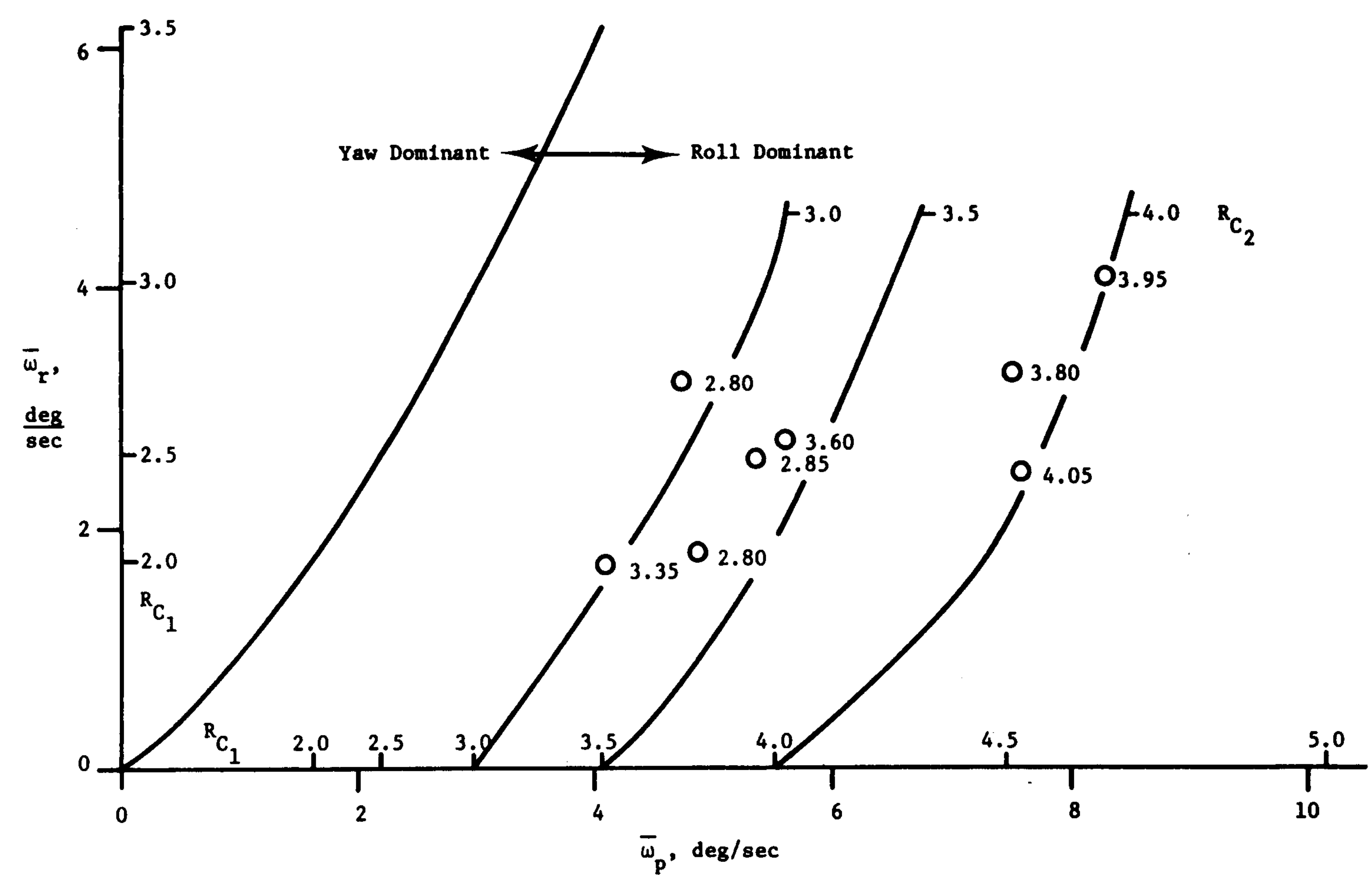

Figure 11.- Ride comfort responses to combined random

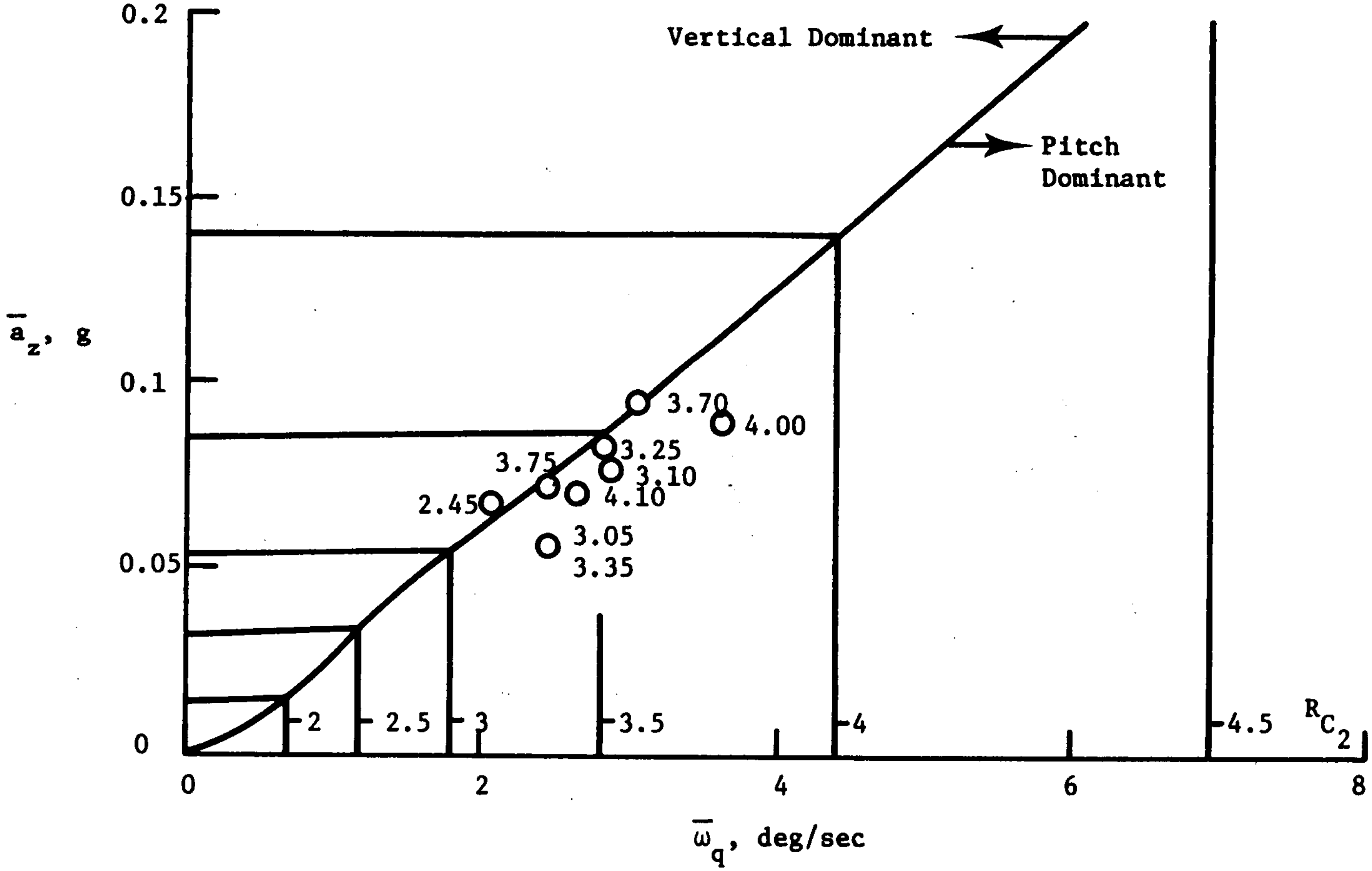

Figure 12.- Ride comfort responses to combined random vertical and pitching motions.

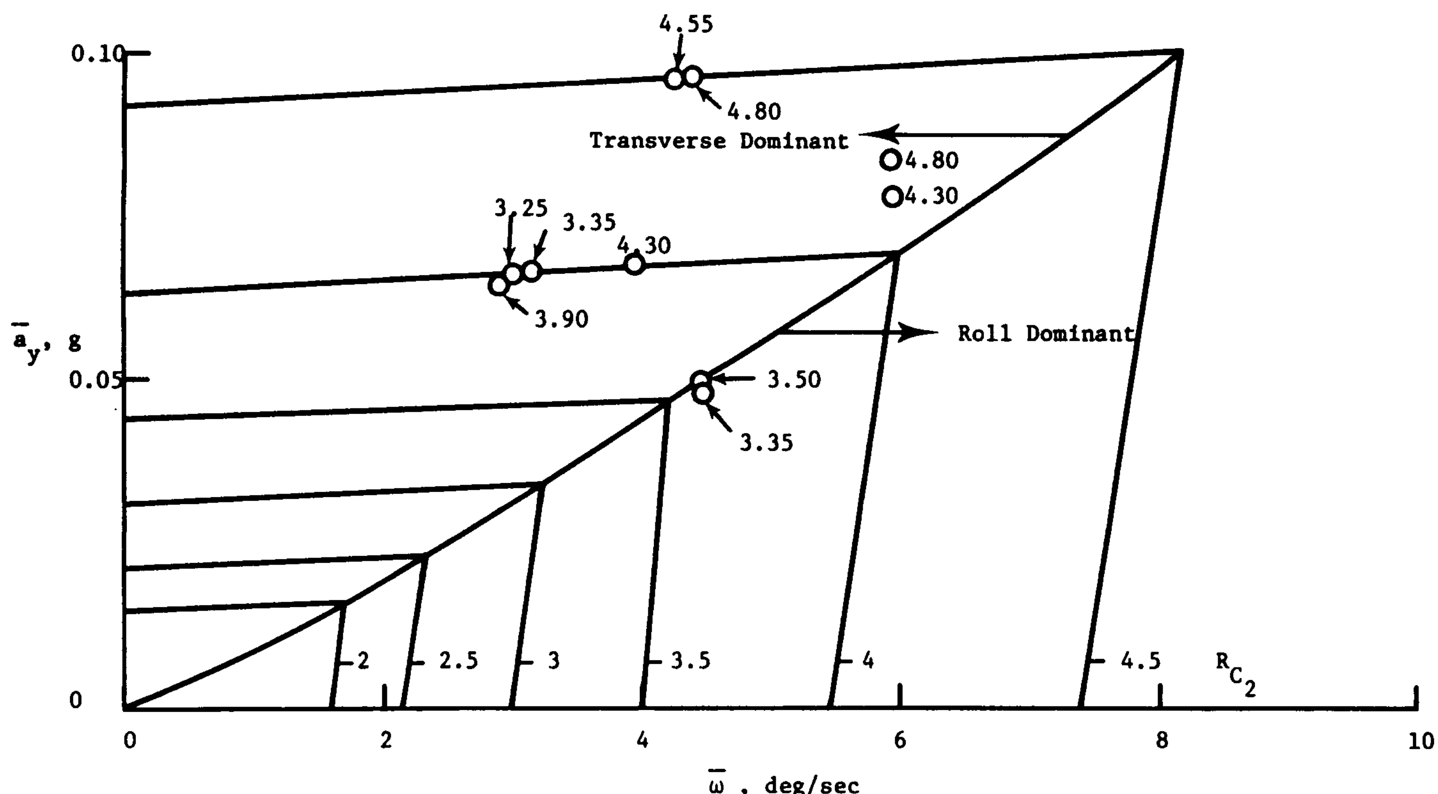

Figure 13.- Ride comfort responses to combined random transverse and rolling motions.

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