Comparison of Passenger-Comfort Models in Buses, Trains, and Airplanes

I. D. Jacobson and R. W. Barber, Department of Engineering Science and Systems, University of Virginia
R. D. Pepler and L. L. Vallerie, Dunlap and Associates, Inc., Darien, Connecticut

Recent controlled experiments concerning passenger ride comfort in intracity buses and intercity trains are reported and compared with past airplane ride-comfort studies. The primary method of analysis is linear regression of environmental and motion factors versus passengers' perceived ride comfort. The regression coefficients so obtained are compared among the three transportation modes for similarities. Transverse acceleration, vertical acceleration, and noise appear to be the dominant determinants of ride comfort in airplanes, roll is the major determinant of ride comfort in buses, and noise and roll are dominant in trains. Despite the differences in the dominant variables, the estimated regression coefficients for the different motions and noise are similar across all three modes. This suggests the possibility of a single general model incorporating all motions and environmental factors.

The modeling of passenger ride quality in transportation systems has received much attention in the past several years. Most of the work can be separated into three general areas. The first of these is laboratory studies that deal mainly with reactions to motion stimuli; the second is field studies that use captive subjects to determine reactions to the general environment (not exclusively motion); and the last is field studies that use fare-paying passengers. These studies have been reviewed elsewhere (1, 2, 3, 4).

Basically, past ride-quality studies have determined the relations between subjective comfort response and motion or multiple stimuli (e.g., motion, noise, and temperature). These models take the form of either equi-sensation-type contours (5) or regression models (6, 7, 8), in which comfort is the dependent variable and the various environmental parameters (such as vertical acceleration, transverse acceleration, roll rate, temperature, and pressure) are the independent variables.

This paper compares ride-quality models developed at the University of Virginia with field studies of both captive and fare-paying passengers on buses, trains, and airplanes. The results for the airplane models are well documented (7, 8, 9, 10, 11, 12) and will not be repeated. Generally, however, those studies were conducted in a manner similar to the bus and train studies described here.

DESCRIPTION OF BUS AND TRAIN EXPERIMENTS

A pair of experiments were performed to develop data on the effects of the environment of a vehicle on passenger comfort in intracity buses and intercity trains. These experiments were designed to simultaneously collect information on the vehicle's environment and the passenger's comfort ratings in that environment. The data on the vehicle's motion were collected by using the University of Virginia's portable environmental measurement system. This equipment consists of a portable measurement box and a standard tape recorder. It is capable of measuring and recording three linear accelerations, three angular rates, temperature, pressure, and noise. Analog measurements are FM-multiplexed on the tape recorder for later retrieval and reduction by analog and digital computers. For the present study, the data so collected were analyzed by using root-mean-square (RMS) values, where deviations are measured against the mean value of the data. This gave a set of RMS values (mean biased out), with the linear accelerations in *g*s and the angular velocities in degrees per second. The test period was subdivided into approximately 1-min segments, each with a somewhat different environmental stimuli. The subjects were asked to rate the comfort of the ride in each of the segments on a scale of 1 to 7, with the following scale characterization:

Comfort Level	Scale
Very comfortable	1
Comfortable	2
Somewhat comfortable	3
Neutral	4
Somewhat uncomfortable	5
Uncomfortable	6
Very uncomfortable	7

The subjects were not coached as to the motion levels that define these comfort levels; all responses were subjective, with the subject himself or herself defining what was comfortable or uncomfortable.

The bus experiment was designed so that the subjects would ride on two different buses, one with a good suspension and one with a poor suspension. A route in the Hartford, Connecticut, area was selected for the experiment such that many different levels of motion would be experienced by the subjects.

The train experiment used four different passenger coaches on the New York to Boston line in the Stamford to New London area. Because it was impossible to control the route in this case, data were gathered at periodic intervals (every 6 min). Again, different coaches were used with different suspension characteristics. The table below shows the experimental design for both the bus and train experiments.

Subject Group	Vehicle Suspension	
	Trial 1	Trial 2
A	Poor	Good
B	Good	Poor

In these experiments, the subject groups were matched for age (young, middle, or older), sex, and frequency of vehicle use (seldom or frequent), and each trial, in which the data were collected over fifteen to twenty 1-min trip segments, was conducted over the same preselected test route.

Table 1. Statistical comparison of bus, train, and airplane motion.

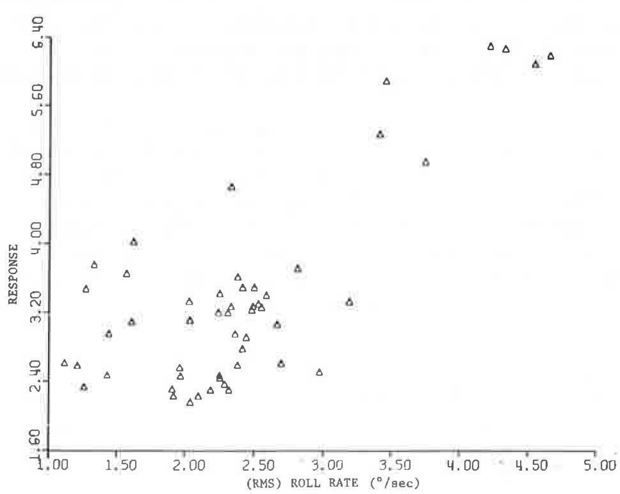
Information	Bus	Train	Commercial Airplane
Subjective response			
Mean	3.4	2.9	3.2
SD	1.1	0.7	0.9
Range	2.2 to 6.3	1.7 to 4.8	2 to 6
Roll rate, °/s			
Mean	2.4	1.4	1.0
SD	0.8	0.3	0.7
Range	1.1 to 4.6	0.9 to 2.6	0.11 to 3.6
Pitch rate, °/s			
Mean	2.1	0.51	0.3
SD	0.5	0.10	0.25
Range	1.2 to 3.4	0.76 to 1.1	0.05 to 2.2
Yaw rate, °/s			
Mean	2.1	1.3	0.26
SD	0.6	0.3	0.37
Range	1.1 to 3.5	0.8 to 2.7	0.009 to 3.6
Longitudinal acceleration, *g*			
Mean	0.044	0.012	0.014
SD	0.015	0.004	0.012
Range	0.017 to 0.073	0.007 to 0.022	0.001 to 0.076
Transverse acceleration, *g*			
Mean	0.075	0.029	0.014
SD	0.028	0.010	0.012
Range	0.031 to 0.134	0.009 to 0.064	0.001 to 0.080
Vertical acceleration, *g*			
Mean	0.082	0.030	0.044
SD	0.027	0.007	0.031
Range	0.036 to 0.152	0.018 to 0.049	0.008 to 0.19
Noise, dB(A)			
Mean	75.8	70.4	87
SD	2.6	4.4	2.7
Range	70 to 83	62 to 82	81 to 94
Temperature, °C			
Mean	22.2	23.3	20.0
SD	1.8	3.6	6.0
Range	18.3 to 23.9	20.0 to 27.8	12.2 to 30.56

Note: °C = (°F - 32)/1.8.

Table 2. Correlation coefficients for bus data.

Item	Subject Response	Roll	Pitch	Yaw	Longitudinal Acceleration	Transverse Acceleration	Vertical Acceleration	Noise	Temperature
Subject response	1.00	–	–	–	–	–	–	–	–
Roll	0.76	1.00	–	–	–	–	–	–	–
Pitch	0.22	0.57	1.00	–	–	–	–	–	–
Yaw	0.05	0.39	0.63	1.00	–	–	–	–	–
Longitudinal acceleration	0.48	0.57	0.50	0.48	1.00	–	–	–	–
Transverse acceleration	0.28	0.59	0.80	0.77	0.61	1.00	–	–	–
Vertical acceleration	0.57	0.71	0.68	0.60	0.62	0.77	1.00	–	–
Noise	0.07	0.28	0.47	0.52	0.25	0.56	0.51	1.00	–
Temperature	-0.08	-0.29	-0.41	-0.35	-0.29	-0.43	-0.29	-0.08	1.00

Figure 1. Mean subject response versus (RMS) roll rate for bus experiment.



RESULTS OF BUS AND TRAIN EXPERIMENTS

Bus

In the bus experiment, environmental data and the responses of 30 subjects were collected for each of 52 road segments. Within each segment, the variation among the individual responses had a standard deviation (SD) of approximately 1.3. The measure used in the following discussion is the mean of the 30 subjects' responses for each segment.

Table 1 summarizes the statistical information gathered in the bus, train, and airplane studies. The data display a relatively wide spread in all of the motion variables. The coefficient of variation for all motion variables exceeds 25 percent; only in the noise variable is the spread much lower, with a coefficient of variation of 3 percent [this, of course, is misleading because the dB(A) measure is logarithmic rather than linear]. The data on pressure are not given because of the insignificant variation in this variable.

Table 2 gives the Pearson correlation coefficients of the mean responses, motion variables, noise, and temperature. The relations among the responses of the subjects and the individual motions can be seen more clearly in Figure 1, which relates the mean response (on the vertical axis) and the mean roll rate (on the horizontal axis) for the collected data.

Because of the high colinearity among the independent motion variables, stepwise linear regression was used to examine their relationship with the dependent variable (comfort). [The stepwise regression technique has been used in similar studies (7) with satisfactory results.]

The results of the regression analysis can be expressed by a comfort-model equation having the following form:

$$C = A + B\omega_R \qquad (1)$$

where

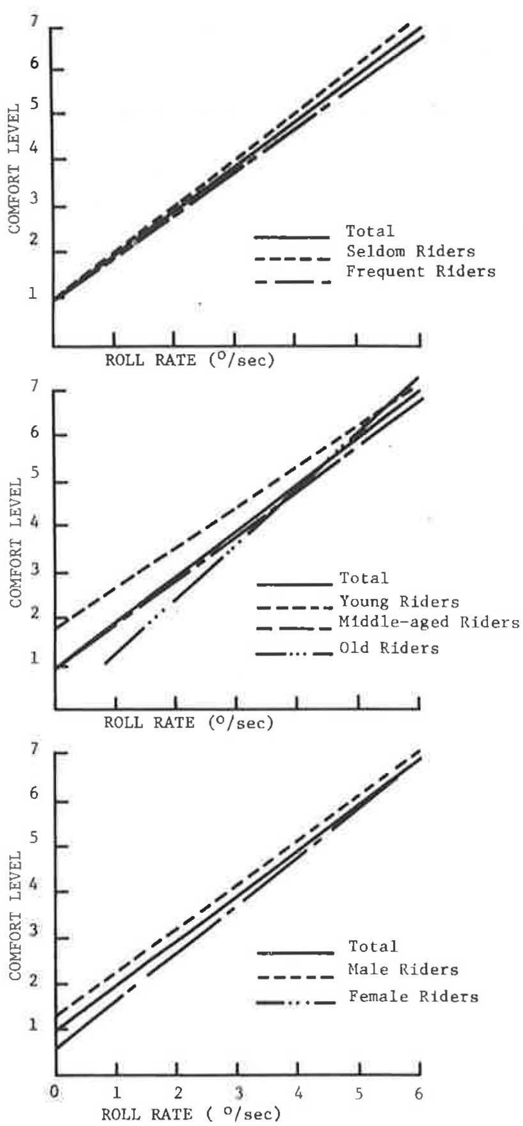
C = comfort rating,
A and B = coefficients, and
ω_R = roll rate (°/s).

Table 3. Comfort models using bus experimental data.

Category of Subjects	A Value	A SE[a]	B Value	B SE[a]	R^2	Level of Significance
All	0.87	0.32	1.05	0.13	0.58	<0.001
Seldom riders	0.79	0.31	1.12	0.12	0.62	<0.001
Frequent riders	0.93	0.33	0.97	0.13	0.53	<0.001
Ages 16 to 24	1.71	0.31	0.91	0.12	0.53	<0.001
Ages 25 to 48	0.84	0.38	1.01	0.15	0.47	<0.001
Ages ≤49	-0.22	0.37	1.28	0.14	0.61	<0.001
Males	1.25	0.31	0.99	0.12	0.56	<0.001
Females	0.47	0.35	1.09	0.14	0.56	<0.001

[a] SE = standard error.

Figure 2. Comfort versus roll rate by category of subject.



The coefficients, R^2 statistics, and levels of significance for all categories of riders are given in Table 3. RMS roll rate is the dominant variable in all cases. It is noteworthy that the R^2 statistic is greater than 0.50 except for the ages 25 to 48 category and that the level of significance in all equations is better than 0.001.

Although the stepwise regression enters yaw, pitch, and vertical acceleration into the equation at the 0.05 level of significance, these variables are not included in the model. The coefficients of these variables are not all positive, a counter-intuitive result. For example, the second variable to enter the equation (for all subjects) is yaw, resulting in the following equation:

$$C = A + B\omega_R - D\omega_Y \qquad (R^2 = 0.65) \qquad (2)$$

where D = coefficient and ω_Y = yaw rate (°/s). The coefficients and standard errors (SEs) for this equation are given below.

Coefficient	Value	SE
A	1.68	0.39
B	1.20	0.13
D	0.55	0.18

It is not realistic that increased yaw in a vehicle's motion will increase the comfort of the passenger for the range of frequencies encountered. These additional terms are therefore not used because they do not reflect a theoretically sound basis for a comfort model.

Graphic representations of the individual regression equations, by category, are shown in Figure 2. Both the constants and the slope coefficients are of interest. The three categories of subjects will be considered separately. First, seldom riders have a lower intercept coefficient, but a higher slope coefficient than do frequent riders; however, these results are not statistically significant because of the relative magnitudes of the standard errors and should only be considered as trends. When subdivided by age, young riders are generally less satisfied with the bus ride, as evidenced by the large intercept coefficient, but are more tolerant of the roll motion; older riders are generally more satisfied with the ride, but are more sensitive to the rolling motion. In the male and female categories, the intercepts are significantly different, but the slopes are not. Males tend to be generally more intolerant of the ride than are females, but their responses to the vehicle motion are approximately the same.

Train

In the train experiment, the responses of 30 subjects were collected on each of 79 track segments. As in the bus analysis, the dependent variable is the mean response of these 30 subjects.

The train data are summarized in Tables 1 and 4. Table 1 gives a statistical summary of the environmental data, including the mean, standard deviation, and range of each variable for the 79 segments. The motion data collected in the train experiment had noticeably less variation than that collected in the bus experiment. For example, the train data have coefficients of variation of 20 and 11 percent for roll and pitch respectively with others in the range of 23 to 35 percent. Table 4 gives the partial correlation coefficients for the train data. The noise level has the highest correlation with the subject responses, and the roll and transverse acceleration have partial correlations of 0.44 and 0.34 respectively.

The stepwise regression approach used in analyzing the train data produced regression equations of the following form:

$$C = A + E\,dB(A) + B\omega_R \quad (3)$$

The coefficients, R^2 statistics, and levels of significance of these equations for all categories of riders are given in Table 5. In these models, the noise and roll variables together explain 52 percent of the total variance in the subjects' responses. The next variable to enter is longitudinal acceleration, which increases the R^2 statistic from 0.52 to 0.54. This small increase does not warrant inclusion in the model, and this variable is not entered.

AIRCRAFT DATA

Data were taken on flights of four different commuter airlines, each flying different aircraft with flight times of 15 to 60 min. The aircraft involved were all small (15 to 30 passengers) and short haul [<800 km (<500 miles)]. In addition, flights onboard an in-flight aircraft simulator were conducted using special subjects to obtain responses to motion environments not experienced in present-day commercial aircraft. These flights are described elsewhere (13). Stepwise linear regression analysis yielded the following models for comfort.

For the commercial flights, the data are summarized in Table 1, and the correlation coefficients are given in Table 6. The motion terms with the highest correlation with comfort are vertical and transverse accelerations and roll. Noise is a smaller contributor; however, it is included here for completeness. Because the comfort equation is nonlinear, two equations were fitted to the airplane data depending on the relative magnitudes of the transverse and vertical accelerations (8). These equations are given below:

$$C = 2.1 + 18.9a_V + 12.1a_T + 0.19[dB(A) - 85.5] \quad (a_V \geq 1.6a_T) \quad (4a)$$

$$C = 2.1 + 1.6a_V + 39.8a_T + 0.19[dB(A) - 85.5] \quad (a_V < 1.6a_T) \quad (4b)$$

where a_V and a_T are vertical and transverse accelerations respectively. For these two equations, $R^2 = 0.41$, and the sample sizes are 2000 and 1680 respectively.

Although no sex-specific or age-specific models have been generated, it has been observed (9, 10) that women are less sensitive to motions than are men.

In the airplane-simulator flights, it was possible to generate motions that allowed the investigation of one variable at a time. In this paper, only the response to roll rate is presented to allow a comparison with ground modes (13):

$$C = 1.34 + 0.76\omega_R \quad (5)$$

where the dominant frequency for the roll motion is 1 Hz. This is chosen to conform with the lowest dominant frequencies of the ground modes. No high-frequency roll-motion data are available because this type of motion does not occur in the air mode.

COMPARISON OF BUS, TRAIN, AND AIRPLANE MODELS

Before proceeding with comparisons of the models them-

Table 4. Correlation coefficients for train data.

Item	Subject Response	Roll	Pitch	Yaw	Longitudinal Acceleration	Transverse Acceleration	Vertical Acceleration	Noise	Temperature
Subject response	1.00	—	—	—	—	—	—	—	—
Roll	0.44	1.00	—	—	—	—	—	—	—
Pitch	0.31	-0.03	1.00	—	—	—	—	—	—
Yaw	0.20	0.62	-0.14	1.00	—	—	—	—	—
Longitudinal acceleration	0.43	0.06	0.18	0.05	1.00	—	—	—	—
Transverse acceleration	0.34	0.56	-0.18	0.77	0.07	1.00	—	—	—
Vertical acceleration	0.08	0.41	-0.38	0.18	-0.05	0.26	1.00	—	—
Noise	0.63	0.15	0.43	0.05	0.46	0.04	-0.13	1.00	—
Temperature	0.24	-0.04	-0.06	-0.03	0.21	-0.03	-0.22	0.27	1.00

Table 5. Comfort models using train experimental data.

Category of Subjects	A		E		B			Level of Significance
	Value	SE[a]	Value	SE[a]	Value	SE[a]	R^2	
All	-5.26	0.96	0.10	0.01	0.96	0.21	0.52	<0.001
Seldom riders	-4.26	0.96	0.08	0.01	1.05	0.22	0.48	<0.001
Frequent riders	-6.30	1.06	0.11	0.01	0.88	0.24	0.51	<0.001
Ages 16 to 25	-5.86	0.94	0.11	0.01	0.81	0.21	0.54	<0.001
Ages 25 to 48	-3.04	1.03	0.06	0.01	1.01	0.23	0.37	<0.001
Ages ≤49	-6.67	0.26	0.12	0.02	1.00	0.28	0.46	<0.001
Males	-6.20	1.09	0.11	0.02	0.86	0.24	0.50	<0.001
Females	-4.33	0.92	0.08	0.01	1.06	0.21	0.50	<0.001

[a] SE = standard error.

Table 6. Correlation coefficients for airplane data.

Item	Subject Response	Roll	Pitch	Yaw	Longitudinal Acceleration	Transverse Acceleration	Vertical Acceleration	Noise	Temperature
Subject response	1.00	—	—	—	—	—	—	—	—
Roll	0.71	1.00	—	—	—	—	—	—	—
Pitch	0.56	0.81	1.00	—	—	—	—	—	—
Yaw	0.30	0.50	0.66	1.00	—	—	—	—	—
Longitudinal acceleration	0.30	0.41	0.54	0.25	1.00	—	—	—	—
Transverse acceleration	0.68	0.86	0.78	0.57	0.40	1.00	—	—	—
Vertical acceleration	0.74	0.91	0.78	0.40	0.39	0.82	1.00	—	—
Noise	0.18	—	—	—	—	—	—	1.00	—
Temperature	-0.13	—	—	—	—	—	—	—	1.00

Figure 3. Normalized lateral-acceleration power spectra for bus, train, and airplane motion.

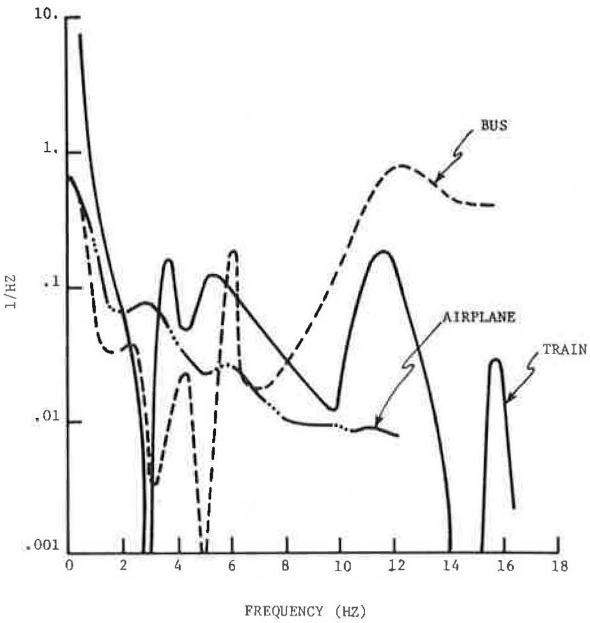
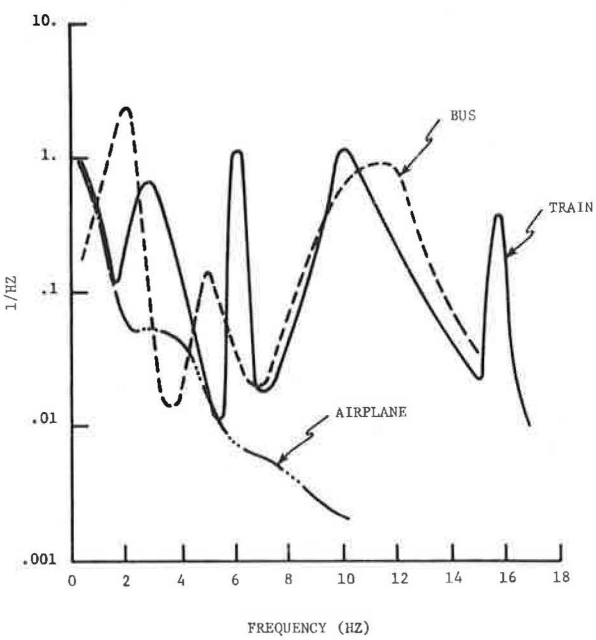


Figure 4. Normalized vertical-acceleration power spectra for bus, train, and airplane motion.



selves, it is important to note several differences in the data. First, the frequency distributions of the three modes are different (Figures 3, 4, and 5). The airplane motion is dominated by low-frequency components (i.e., <2 Hz) for roll rate and vertical and lateral acceleration, but the bus motion, and to a lesser extent the train motion, have more high-frequency components. A second difference is the range of motion encountered for the three modes. Table 1 indicates that there is less angular motion on the airplane than on the ground modes. In addition, there are significantly higher noise levels on board the aircraft. Of course, as in any regression analysis, caution should be used in applying the models to situations outside the range of the experimental data.

Figure 5. Normalized roll-rate power spectra for bus, train, and airplane motion.

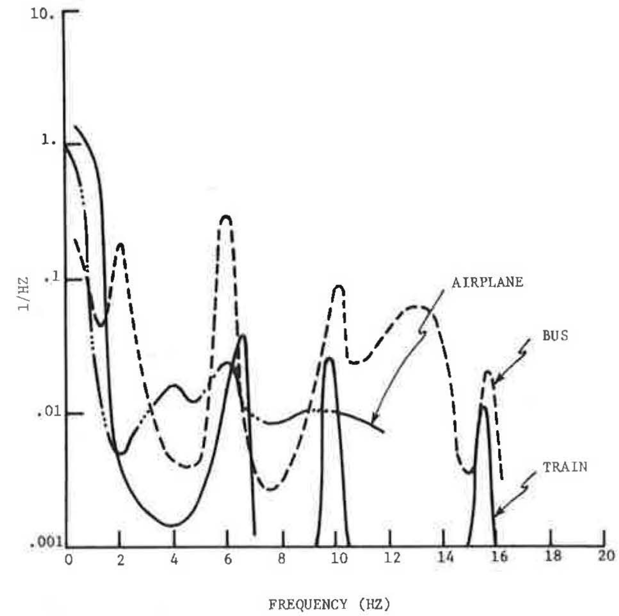


Table 7. Regression coefficients by mode and motion.

	Stimulus			
Vehicle Type	Roll	Vertical	Transverse	Noise
Bus	1.05 ± 0.13	16.6 ± 5.2[a]	—	—
Train	0.96 ± 0.21	—	28.6 ± 8.5[a]	0.10 ± 0.01
Airplane ($a_v \geq 1.6a_l$)	0.76[a]	18.9 ± 1.0	12.1 ± 0.2	0.19 ± 0.03[a]
Airplane ($a_v < 1.6a_l$)	—	1.6 ± 0.7	39.8 ± 8.6	0.19 ± 0.03

[a] Not an important variable for mode.

Although the models obtained are somewhat different in nature, they do have similarities. However, as regression models apply only within the limited range for which there are data, it is not surprising that different travel modes have different regression models. These differences suggest an examination of the influences of the environmental variables. In Table 7, four variables—roll rate, vertical acceleration, transverse acceleration, and noise—are compared. The three major models are summarized below:

1. Bus: $C = 0.87 + 1.05\omega_R$,
2. Train: $C = -5.27 + 0.96\omega_R + 0.10dB(A)$, and
3. Airplane: $C = 2.1 + 18.9a_v + 12.1a_T + 0.19\,[dB(A) - 85.5]$ for $A_v \geq 1.6a_T$ and $C = 2.1 + 1.6a_v + 39.8a_T + 0.19\,[dB(A) - 85.5]$ for $a_v < 1.6a_T$.

Within the statistical accuracies given (and remembering that some of the variables are secondary influences for a particular mode), the agreement is good. The roll coefficients are similar, with those for bus, train, and airplane all in the range of 0.76 to 1.05. The vertical coefficient for the bus data (16.6) lies between the coefficients for the two airplane models. This is a reasonable result, with the a_v/a_T ratio for the bus and train motion approximately unity (Table 1). Because this is close to the changeover point of a 1.6 ratio in the airplane equations, it is unclear which of the two airplane equations should be used in the comparison. There is a similar result in the transverse accelerations, where the train coefficient of 28.6 lies midway between the airplane coefficients of 12.1 and 39.8. The noise

Table 8. Roll-rate regression coefficients for bus and train data.

Category of Subjects	Bus Data Value	Bus Data SE[a]	Train Data Value	Train Data SE[a]
All	1.05	0.13	0.96	0.21
Seldom riders	1.12	0.12	1.05	0.22
Frequent riders	0.97	0.13	0.88	0.24
Ages 16 to 24	0.91	0.12	0.81	0.21
Ages 25 to 48	1.01	0.15	1.01	0.23
Ages <49	1.28	0.14	1.00	0.28
Males	0.99	0.12	0.86	0.24
Females	1.09	0.14	1.06	0.21

[a] SE = standard error.

coefficients of 0.19 for airplane and 0.10 for trains are also in the same range, although statistically different (at a 0.05 level of significance). Table 8 gives additional information on the roll coefficients for bus and train subject subpopulations by age, sex, and frequency of ridership. Here again there is substantial agreement between the bus and train modes.

SUMMARY AND CONCLUSION

The data presented suggest that passenger sensitivity to the different vehicle motions are similar, regardless of the mode. Because of the dissimilarities in the dominant motions and in the frequency ranges encountered, conclusions beyond this must necessarily be guarded. Nonetheless, the results presented show a similarity in the marginal response to linear and angular motions that is reasonable from a physiological point of view and suggests the possibility of a general model of ride comfort that might be used on a variety of transportation modes. This general model might take the form of a multivariate model in which different motions and environmental factors are included or excluded depending on their relative dominance. This speculation is not unreasonable, given the similarity of the regression coefficients in the bus, train, and airplane ride-comfort models.

ACKNOWLEDGMENT

This work was sponsored in part by the Transportation Systems Center, U.S. Department of Transportation.

REFERENCES

1. A. R. Kuhlthau and I. D. Jacobson. Investigation of Traveler Acceptance Factors in Short-Haul Air Carrier Operations. Proc., Symposium on Vehicle Ride Quality, Langley Research Center, National Aeronautics and Space Administration, Hampton, Va., Technical Memorandum X-2620, Oct. 1972.
2. Ride-Quality Symposium and Workshop. Proc., National Aeronautics and Space Administration, Technical Memorandum X-3295; U.S. Department of Transportation, Rept. DOT-TSC-OST-75-40, Nov. 1975.
3. I. D. Jacobson. Criteria for Ride Quality—Motion. Short-Haul Air Transportation Program, Department of Engineering Science and Systems, Univ. of Virginia, Charlottesville, Memorandum Rept. 403202, Feb. 1972.
4. I. D. Jacobson. Environmental Criteria for Human Comfort—A Study of the Related Literature. Research Laboratories for the Engineering Sciences, Univ. of Virginia, Charlottesville, Rept. BE-4088-101-74; National Aeronautics and Space Administration, Contractor Rept. 132424, Feb. 1974.
5. T. K. Dempsey. A Model and Predictive Scale of Passenger Ride Discomfort. National Aeronautics and Space Administration, Technical Memorandum X-72623, Dec. 1974.
6. R. W. Stone, Jr. Simulator Studies and Psychophysical Ride Comfort Models. Proc., Ride-Quality Symposium and Workshop, Williamsburg, Va., National Aeronautics and Space Administration, Technical Memorandum X-3295; U.S. Department of Transportation, Rept. DOT-TSC-OST-75-40, Nov. 1975, pp. 615-664.
7. I. D. Jacobson and L. G. Richards. Ride-Quality Evaluation 2: Modeling of Airline Passenger Comfort. Ergonomics, Vol. 19, No. 1, 1976, pp. 1-10.
8. I. D. Jacobson. Construction and Verification of a Model of Passenger Response to STOL Aircraft Characteristics. Paper presented at SAE National Air Transportation Meeting, New York, Paper No. 760525, May 18 to 20, 1976.
9. L. G. Richards and I. D. Jacobson. Ride-Quality Evaluation 1: Questionnaire Studies of Airline Passenger Comfort. Ergonomics, Vol. 18, No. 2, March 1975, pp. 129-150.
10. L. G. Richards and I. D. Jacobson. Ride-Quality Assessment 3: Questionnaire Results of a Second Flight Program. Ergonomics, Vol. 20, No. 5, 1977, pp. 499-519.
11. I. D. Jacobson and A. N. Rudrapatna. The Effect of Interior Cabin Noise on Passenger Acceptance. Paper presented at the 1976 SAE Business Aircraft Meeting, Wichita, Kan., Paper No. 760466, April 6 to 8, 1976.
12. I. D. Jacobson, A. R. Kuhlthau, and L. G. Richards. Application of Ride-Quality Technology to Predict Ride Satisfaction for Commuter-Type Aircraft. Proc., Ride-Quality Symposium and Workshop, Williamsburg, Va., National Aeronautics and Space Administration, Technical Memorandum X-3295, U.S. Department of Transportation, Rept. DOT-TSC-OST-75-40, Nov. 1975, pp. 209-436.
13. E. W. McClurken, Jr. Acquisition of Passenger Ride-Quality Data Aboard the Total In-Flight Simulator (TIFS). Short-Haul Air Transportation Program, Technical Rept. 403220; National Aeronautics and Space Administration, Contractor Rept. 145957, Oct. 1975.