REPORT NO. DOT-TSC-OST-76-54

EXPERIMENTAL DESIGNS AND PSYCHOMETRIC TECHNIQUES FOR THE STUDY OF RIDE QUALITY

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MAY 1977

FINAL REPORT

Prepared for

U.S. DEPARTMENT OF TRANSPORTATION
OFFICE OF THE SECRETARY
Office of the Assistant Secretary for
Systems Development and Technology
Office of Systems Engineering
Washington DC 20590

Technical Report Documentation Page

1. Report No.
DOT-TSC-OST-76-54

2. Government Accession No.

3. Recipient's Catalog No.

4. Title and Subtitle
EXPERIMENTAL DESIGNS AND PSYCHOMETRIC TECHNIQUES FOR THE STUDY OF RIDE QUALITY

5. Report Date
May 1977

6. Performing Organization Code

7. Author(s)
M. Dean Havron, Robert A. Westin

8. Performing Organization Report No.
DOT-TSC-OST-76-54

9. Performing Organization Name and Address
ENSCO, Inc.*
5408A Port Royal Road
Springfield VA 22151

10. Work Unit No. (TRAIS)
OS749/R7505

11. Contract or Grant No.
DOT-TSC-864

12. Sponsoring Agency Name and Address
U.S. Department of Transportation
Office of the Secretary
Office of the Asst. Sec. for Sys. Dev. and Tech.
Office of Sys. Eng., Washington DC 20590

13. Type of Report and Period Covered
Final Report
July 1974 - July 1975

14. Sponsoring Agency Code

15. Supplementary Notes
*Under Contract to: U.S. Department of Transportation
Transportation Systems Center
Kendall Square
Cambridge MA 02142

16. Abstract
A major variable in both the cost of any new transportation system and rider acceptance of the system is the ride quality of its vehicles. At this time, there exists no set of objective criteria which would allow the transportation system designer to determine what level of ride quality would be considered acceptable by a wide variety of potential passengers. The purpose of this study was to establish statistically acceptable techniques for the development of methods for relating physical measures of vehicle vibration to passenger estimates of ride quality.

The major end products of this study are:

1. A general experimental strategy which will allow for the correlation of data from experiments performed in different settings and on different transportation modes.
2. A set of experimental designs for the statistically valid measurement of ride quality.
3. A set of psychometric scales for the determination of perceived ride quality.
4. The results of a validation test of the psychometric scales. This test was performed on a ride simulator which was programmed to duplicate the ride experienced on an interurban train.

17. Key Words
Vehicle Vibration, Ride Quality, Surface Transportation, Experimental Designs, Psychometric Scales, Ride Simulator.

18. Distribution Statement
DOCUMENT IS AVAILABLE TO THE U.S. PUBLIC THROUGH THE NATIONAL TECHNICAL INFORMATION SERVICE, SPRINGFIELD, VIRGINIA 22161

19. Security Classif. (of this report)
UNCLASSIFIED

20. Security Classif. (of this page)
UNCLASSIFIED

21. No. of Pages
308

22. Price

Form DOT F 1700.7 (8-72)

Reproduction of completed page authorized

PREFACE

This effort was performed by ENSCO, Inc. with Human Sciences Research Inc. as a subcontractor. ENSCO, Inc. took responsibility for the selection, editing, and recording of the train rides and the computer analysis of the data. Human Sciences Research, Inc. was responsible for the behavioral science portions of the effort including the proposed experimental designs and the conduct of the experimental work reported.

This effort was performed under contract number DOT-TSC-864 for the Transportation Systems Center. This contract was part of the Ride Quality of Transportation Systems project conducted by TSC as part of the Transportation Advanced Research Program conducted by the Office of Systems Development and Technology, Office of the Secretary of the Department of Transportation.

The authors are indebted to NASA - LaRC for the use of the PRQA and in particular to S. A. Clevenson and his technicians who were responsible for its operation. They also are indebted to R. O'Connor for her assistance in the conduct of the experiments, and to E. D. Sussman and C. N. Abernethy of TSC for their contributions in program direction and technical suggestions.

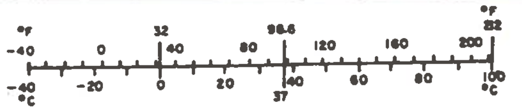
METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (weight)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (weight)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



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1. INTRODUCTION AND SUMMARY

1.1 OBJECTIVES

The objectives of this study were to design the experiments and develop the psychometric scaling tools required for the objective investigation of the ride quality of surface transportation vehicles. Particular emphasis was placed on the development of methodology to reliably relate passengers' perceptions of ride quality to the physical motions and vibrations of the vehicle.

The structure of this report follows the approach that was taken in the performance of the study. The results of the following four major tasks are described in detail:

Analysis: Review previous research to determine those areas which require additional investigation; develop general hypotheses relating vehicle vibrations to passenger perceptions of ride quality; and develop a general strategy for planning ride quality research.

Synthesis: Translate this strategy into a series of experimental designs which may be used to obtain statistically valid data which relates ride quality as evaluated by passengers to physical measures of vehicle dynamics.

Developmental: Develop psychometric scales which will provide for comprehensive rating of perceived ride quality.

Validation: Participate in a validation test of the use of these rating scales for a single transportation concept.

1.2 EFFICIENCY AS A CRITERION

The primary objective in the planning of research is to assure the efficiency of the experiments. A general research strategy is required so that the work may progress as a series of experiments, each of which supports the next, and so that the growing body of data on vehicles studied can be fully utilized to predict ride quality of new and modified vehicles with increasing accuracy and economy. A generalized model of ride quality is presented which provides a conceptual framework for establishing the objectives of experiments and the order in which they should be performed. The results of previous research have been evaluated in the context of this model and specified areas have been identified where the model must be supported by additional experimental data.

A set of experimental designs has been developed both to demonstrate how this required data may be efficiently obtained and to collect data for the first vehicle to be studied--interurban trains. These experiments include laboratory investigations of the reactions of people to controlled vibrations on a ride simulator, controlled field experiments with paid subjects on operational vehicles, and investigations of the expectations and requirements of ride quality by fare-paying passengers. This prototypical set of experimental designs should, with modifications, be adequate for the investigation of the ride quality characteristics of any of the twelve types of vehicles discussed in this report, or any new type of vehicle which may be proposed.

The experimental designs proposed in this study are by necessity general in their approach to the study of ride quality. Previous research has generally been directed to the testing of limited psychophysical hypotheses or to the general question of whether passengers can discriminate between different rides. Because of differences in terminology and methodology among these studies, a great deal of ambiguity remains which limits the usefulness of the reported results. The experimental designs which are proposed in this report are used to test the basic assumptions of a generalized model relating vehicle ride to perceived ride quality. Such a validated model is needed to provide a firm basis for the interpretation of the results of experiments conducted in the rather uncontrolled experimental environment of an operational, revenue service, transportation vehicle.

The potential efficiency to be realized if results from one type of vehicle can be used to accurately forecast results from another is an important aspect of the experimental strategy. By constantly comparing the predicted relationships between ride and ride quality of a new vehicle to relationships determined empirically on a similar vehicle, then retrospectively adjusting coefficients or multipliers, we expect to successively reduce the errors of forecasting and the need for experiments as work proceeds.

1.3 END PRODUCTS

The major end products of the current study include:

1. A general experimental strategy. The efficient investigation of ride quality requires that full use be made of the results of previous research. Additional experiments that are required must be conducted in such a way that each builds on the results of previous experiments in the series.

2. A set of experimental designs. These provide the specific methodology for the conduct of experiments as required to implement the general strategy. These specific experiments are designed to result in the statistically valid measurement of the ride quality of present and proposed ground transportation vehicles.

3. A set of psychometric scales for the determination of perceived ride quality. Scales for measurement of responses to vibration have been tested under controlled conditions of a ride simulator, and the limitations, as well as the

repeatability and reliability, of the scales are documented.

4. The results of a validation experiment which used the psychometric scales to determine the perceived ride quality of a vibration environment on a simulator. The simulator was programmed to duplicate, in three degrees of freedom, the various rides experienced on an interurban train as a function of track structure.

2. A GENERAL RIDE-RIDE QUALITY MODEL

2.1 CONSTITUENTS OF THE MODEL

Concepts from three fields--system analysis, design of ground transportation vehicles, and human factors--have been applied to develop a model which relates the motions of a vehicle and habitability to the passenger's evaluation of the comfort and acceptability of the ride.

Terms and concepts applied throughout this report are as follows:

1. Transportation System. Current and proposed ground transportation systems are classified into groups based on similarities of vehicle and guideway technology. Experimental designs are prescribed for the investigation of ride quality of twelve existing and proposed systems. These experiments may be modified to apply to any new system developed.

2. Ride. By ride, we refer to the physical environment created in the vehicle interior when it moves along a guideway from its point of origin to its point of destination. This environment may in turn be subdivided into three major components:

   a. Vibration. By vibration, we mean all dynamic motion of the vehicle, i.e., mean accelerations in the vertical, lateral, and pitch, roll and yaw; and various combinations of these, for example, jerk, sway, etc. The physical characteristics of the vibration are denoted by the symbol D_V.

b. Habitability. Habitability refers to the physical aspects of the design of the interior of the vehicle and of the control of the vehicle environment. Seat design and control of air temperature and ventilation would be examples. The symbol D_H is used for the habitability design factors.

c. Operational Factors. Operational factors, as defined here, are those factors which are <u>not</u> under control of the designer of a vehicle or guideway. They arise in the operation of vehicles, in attention given to passengers, and in such items as trip time, costs, etc. The symbol O is used for the operational factors.

Taken together, the above three factors define the stimulus domain of a vehicle. Appendices I, II, and III contain a detailed discussion of each of these factors.

3. Ride Quality. We turn next to the passengers' perceptions and evaluations of the ride. Passengers respond to the vibration environment in terms of an evaluation of comfort symbolically V_c. Similarly, passengers respond to and evaluate the interior design of the vehicle, again in terms of comfort, H_c. Operational factors are perceived and evaluated. These are referred to as O_s, i.e., satisfaction as a function of operational factors. Taken together, these factors define the response domain, i.e., perceived ride quality as a function of all of the stimulu factors.

The characteristics and applications of the ride quality crite are worthy of note. Subjects may be expected to differ in the they evaluate ride quality. The reported evaluations may be thought of as the sum of the evaluations of a number of facto and the sum of these individual differences will result in a

Gaussian distribution of ride quality evaluations.* The experimenter can use the distribution of evaluations by samples of riders to compare rides that differ with respect to vibration, habitability or operational factors. Segments of a ride wherein guideways differ with respect to roughness can be compared. Or, one can compare responses of riders who differ with respect to sex, age, or prior experience. Whatever the factors compared, the effect of differences in the stimulus will be reflected in changes in the mean value of the perceived ride quality as calculated from the judgments of a number of different passengers. In all cases, the relationship between the ride and the perceived ride quality will be a function of the effect and interaction of all of the stimulus factors as summarized in Figure 2-1.

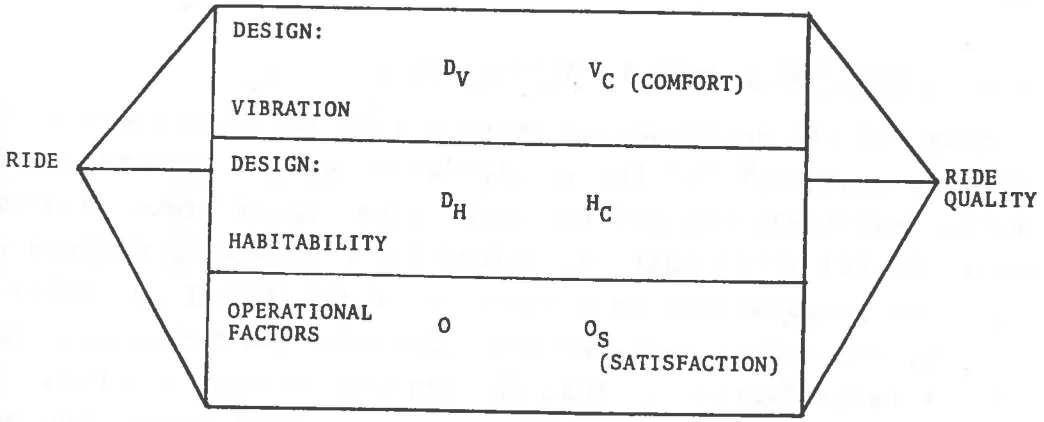

Figure 2-1. General Ride-Ride Quality Model

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*Whether the distributions are skewed depends in large measure on the scale used to measure ride quality. We assume for the moment that evaluations across samples of passengers are normally distributed.

The objective of the research being planned is to establish the relationships between stimulus and response at the gross level (i.e., ride related to ride quality), for vibration, habitabilit and operational factors, and down to the sub-components of ride which are functionally related to judgments or evaluations of comfort. However, while relationships are visualized here in pairs--a stimulus factor related to a response--passengers may not combine and integrate their impressions in the way we have indicated.

This study does not directly address operational factors, as they are beyond the control of designers of vehicles and guideways. However, passengers asked to evaluate ride quality may be more influenced by factors such as delays in schedules than by vibration or habitability. Consequently, the (possible) influence of operational factors on the perceptions of ride and ride quality cannot be ignored.

2.2 GENERAL REQUIREMENTS OF THE MODEL

A model of the relationship between ride and ride quality provides a framework for the incorporation of the results of previous investigations and the identification of areas requiring experimental investigation. Since the passenger's comfort or level of satisfaction is a function of the vibration, habitability and operational factors, the model must also incorporat all of these factors so that the effects of each and their inte actions can be estimated. In the most general sense, the model may be used to generate hypotheses in the statistical evaluatio of experimental results. Therefore, the model must be subject to experimental confirmation. As experimental results are accu mulated, relationships between ride and ride quality parameter will be established from components to the more general levels one vehicle at a time.

The model also provides guidance for the computation of correl tions between these measures of the stimulus and response envi ments. The model must allow for possible interactions between ride evaluations and the possible masking of weaker variables by stronger variables.

Most importantly, the model must give direct information of the relationships between ride and ride quality. This information must be in a form that is directly applicable to the establishment of ride quality specifications for ground transportation vehicles. Therefore, the model must furnish predictions of the passenger's acceptance of a proposed ride. These predictions must be in terms which are applicable to the evaluation of the cost-effectiveness of changes to the vehicle suspension system, guideway, characteristics, or other factors affecting the ride of the vehicle.

Ultimately, the passengers' ride quality perceptions provide an external criterion for vehicle design. The analytical techniques which are used to predict the ride of the vehicle can then be constantly checked in terms of this criterion that is external to the engineering measurements of vibration, habitability, and operational factors.

2.3 CLASSIFICATION OF THE STIMULUS PARAMETERS

A general model of ride-ride quality requires that all of the physical factors influencing the perceptions of ride quality be defined and, if possible, quantified. These include vehicle design, vibration, habitability factors, and operational factors. The criterion of experimental efficiency also requires that various transportation vehicles be classified according to similarities of these factors so that results can be extended to vehicles other than those specifically investigated.

2.3.1 VEHICLE VIBRATION AND ACCELERATIONS

Of primary importance to the present study is the definition of vehicle motions which affect the comfort of the passengers and the acceptability of the ride.

2.3.1.1 Sources of Vehicle Vibration

Guideway Irregularities as a Source of Vehicle Vibration

In the broadest sense, a guideway consists of any surface over which the vehicle rides, whether it be terrain, air, water, or a man-made restrainer. As a vehicle moves, its forward motion combines with guideway irregularities to transmit vibration into the vehicle. In the case where the vehicle has wheels, the vibration is imparted directly to the wheel, passes through and is modified by the suspension system, and becomes manifest in the passenger compartment. Here it is perceived by human subjects, who then judge the quality of the ride.

A common feature of all guideway types is a kind of motion which is best described as random. Much of the previous research in ride quality has characterized this random variation as a stationary ergodic process. In actual practice, it is possible to use this characterization only to a limited extent. Guideway characteristics will generally be dependent upon location. These will be rougher in some places because of local unevenness or instability of the supporting structure and they will be smoother where more stable conditions prevail.

Considerable effort has been extended in understanding the statistics of man-made guideways, particularly railway track, highways, and airport runways. The basic finding that is common to all of these is given as follows:

> There is an underlying Gaussian random process which is stationary in nature and which is characterized by a power spectral density. This power spectral density is generally of the form:
>
> $$S(f) = \frac{A}{f^2}$$
>
> where A is a constant relating to the amplitude, and f is the spatial frequency in cycles per unit distance.

> Usually, man-made guideways are constructed out of segments of fixed length such as steel rails or concrete slabs. They may also be supported by periodic structures, or aligned by a periodic survey. All of these properties introduce repetitive motions to the vehicle. Studies have shown that these periodic deviations can introduce both deterministic periodic and periodically introduced random variation of guideway geometry. These periodic variations will be a major cause of vibrations for any vehicle using such a guideway.

Motion of the vehicle cabin is itself a function of the suspension. Suspension characteristics are modified by:

> Wheel spacing and distribution in rolling vehicles; distribution of load and support forces in other types of vehicles.
>
> Spring, damper, and inertial characteristics of the various suspension elements.
>
> The mass distribution and flexibility of the vehicle body itself.

If the suspension characteristics of the vehicle are linear, the various components of guideway behavior remain essentially unaltered. That is, the random variations in the guideway structure are transmitted through the suspension and appear as random vibrations applied to the passengers. Periodic components similarly remain periodic all the way through to the passenger. Finally, the periodically introduced random components are also transmitted through the vehicle suspension system as periodically introduced random components, although the suspension system may significantly alter the frequency distribution and duration of these components.

If the suspension characteristics are nonlinear, as in the case of the actively controlled suspension systems proposed for Maglev vehicles, the analytical form of the relationships between guideway irregularities and the vehicle ride becomes more complex. However, the relationships will remain deterministic and for the purposes of analysis can be described in either mechanistic or statistical terms.

The options which are available for controlling the effect of guideway irregularities on the ride of the vehicle are given as follows:

- Guideway improvement
- Limitation of speed
- Changes or redesign of the vehicle suspension, including the characteristics of the seating provided for passengers.

Onboard Equipment as a Source of Vibration

Equipment mounted on transportation vehicles can be responsible for contributing to the vibration environment. Examples of such sources are given as follows:

- Propulsion equipment and gear trains
- Compressors
- Air conditioning system
- Motor generators
- Out-of-round/out-of-balance wheels

These sources can be further categorized according to whether they are speed-dependent or speed-independent, and whether their operation is continuous or intermittent. In either event, these vibrations will tend to be of the continuous periodic type. For intermittent machines, there will be transients which can be either impulsive or smeared-impulsive in nature.

Effect of Guideway Design and Vehicle Operation on the Ride

Operational accelerations are introduced into the ride because of the need to perform start/stop operations, negotiate a prescribed path, or avoid obstacles. Guideway design characteristics which affect the ride are bridge approaches, intersections, interchanges, and branching points such as turn-outs in railway track, and lane changes as negotiated by automotive vehicles. All of these design characteristics are deterministic and are under the control of the design engineer or the vehicle's operator.

2.3.1.2 Engineering Characterization of Vehicle Motions

The ride of a vehicle can be characterized in engineering terms as time-dependent accelerations in three translational and three rotational degrees of freedom. The efficient analysis of the ride requires that it be defined in terms of parameters such as the direction, frequency, and amplitude of the accelerations. The resulting description will not necessarily be one which can be understood by most of the passengers. The analysis of the relationship between ride and ride quality must relate engineering parameters to passenger perceptions. The equivalence between engineering terms and passenger-related terms must be established so that the findings of the psychologist may be translated into the language of the engineer.

The vibration arising from onboard equipment and from irregularities in the guideway will be more or less continuous. This vibration can therefore be described in terms of average frequency, amplitude, and periodicity. The accelerations arising from guideway design characteristics can be more accurately described as discrete events which are superimposed on the constant vehicle vibration. The analytical description of these events is not as straightforward as for the continuous vibration case. Each event must be characterized in terms of frequency, amplitude, duration, and the time-dependent changes of these parameters. The repetition of the events must also be considered in terms of the mean and stochastic distribution of the interarrival time.

There are no generally accepted criteria for defining the characteristics of a ride of a vehicle in terms of continuous vibration and discrete events, although such a description would seem to be consistent with the way the ride is described by passengers. Until the definition of an event can be described in mathematical terms that are consistent with a fundamental model of how the events are perceived, we are limited to describing features of the ride in terms of their frequency distribution, amplitude, and other basic physical parameters. Such a scheme will at least provide a basis for determining whether the standard analytical techniques such as spectral analysis will be adequate to describe the ride.

An example of one possible classification scheme based on vibrational frequency and repetition characteristics is shown in Table 2-1, along with examples of each type of ride characteristic. It should be noted that almost all previous psychophysical research in ride quality has investigated continuous periodic vibration, which is also the only one of the classes of vibration for which there are adequate analytical tools based on averaging techniques such as RMS, peak amplitude, and spectral (frequency domain) analysis. All of the other classes of vibration require time-domain analysis. Physical fatigue may be considered the result of the average vibration environment experienced by a passenger. All other characteristics of the ride are evaluated in terms of comfort or acceptability at a particular moment of time, with emphasis probably placed on the most recent environmental conditions.

Previous research has concentrated on continuous periodic vibration for two apparent reasons--analytical tools are readily available, and ride simulators have been controllable only in terms of frequency and amplitude. The results of much of this work may be valid in terms of the limited environmental conditions investigated in the laboratory. However, questions remain as to whether the laboratory results can be used to accurately forecast ride quality evaluations made by fare-paying passengers aboard operational vehicles.

Table 2-1. Types of Vehicle Motion in Terms of Frequency Content of the Motions

	Periodic	Random
Continuous	Vibration with a line spectrum.* Most of the energy is concentrated at frequencies greater than 6 Hz. Examples: Vibrations from vehicle machinery Out-of-round wheels Corrugations on guideways	Vibration with a broadband spectrum.* Most of the energy is concentrated at frequencies greater than 6 Hz. Examples: Guideway irregularities NOT associated with periodic structure.
Impulsive	Regularly occurring events whose repetition rate is less than 2-3 Hz and whose energy is concentrated in line spectrum* components greater than 6 Hz. Examples: Traversing sharp, well-defined guideway segmentations such as pavement joints or rail joints. Flat spots on wheels	An isolated transient event whose energy is concentrated in a broadband spectrum* and at frequencies greater than 6 Hz. Examples: Pothole or severe guideway irregularity at bridge, interchange, etc. Guideway hits for air on magnetically suspended vehicles.
Smeared	A repetitive event whose repetition rate and whose spectral lines are principally below 6 Hz. Examples: Rock and roll type motions, less than 3 Hz--includes lateral sway and heavy motions associated with periodic guideway structure.	An isolated transient event whose spectrum* is principally below 6 Hz. Examples: Stop and start motions Lane changes Curving, with and without banking Most other design characteristics of guideway and ride

* Spectrum is defined as the acceleration frequency components. These are derived by narrow-band filter analyzer or by Fourier analysis. A line spectrum is one in which most of the energy is concentrated in a few narrow frequency bands, resulting in peaks in the plot of power vs. frequency for the vibration environment.

The characterization of the vibration environment in engineering terms must be comprehensive. Important features of the ride that may affect its acceptability by passengers must not be ignored. Averaging and mathematical techniques such as spectral analysis have been widely used due to their ease of computation. These techniques assume that the ride is statistically stationary and ergodic, and their use to describe the ride of real vehicles may result in inaccuracies where these assumptions are not met. Other similar techniques such as RMS and peak amplitude analysis also lose the time-domain information which is an important characteristic of the event characteristics of the ride.

Power spectral density analysis and similar averaging techniques are adequate for only the continuous portion of the ride. The investigation of the effect of impulsive and smeared-impulsive events on the passenger's acceptance of the ride must use time-domain criteria to classify these features of the ride.

The value of the analytical technique used to describe the ride should be based on whether it can predict the relative comfort or acceptability of a ride at any instant, and whether these point estimates of comfort can be integrated to give an overall comfort rating similar to that reported by the passengers. This suggests that the analysis of the ride in mathematical terms should be based on some model of the psychological evaluative process. For instance, a simple model may assume that the comfort index at any instant is an exponentially smoothed function of the RMS history of the ride to that instant, weighted in terms of frequency and amplitude according to the frequency and amplitude sensitivities of the human body. The overall average rating for a segment of ride would then be the integral of these instantaneous ratings weighted to compensate for the effects of primacy and immediacy (i.e., the beginning of the ride may affect the overall psychological set of the passenger, the end of the ride may be remembered most clearly, and the middle of the ride may be remembered less clearly).

In mathematical terms, such a comfort index might be defined as

$$Q_T = \frac{1}{T} \int_o^T A_{rms} F_{rms} e^{-c(T-t)} rms_t \, dt$$

where Q_T = comfort index at time T

rms_t = energy equivalent of the vibration at time t

A_{rms} = perceived comfort of vibration as a function of rms amplitude

F_{rms} = perceived comfort of vibration as a function of frequency of vibration

c = constant related to the immediacy effect of prior vibrational history

$$\overline{Q} = \frac{1}{T} \int_o^T W_t Q_t \, dt$$

where $\overline{Q}$ = average comfort of ride

W_t = weighting factor as function of t to account for immediacy and primacy effects

It is not within the scope of the present study to evaluate the usefulness of this proposed ride comfort index, nor the usefulness of any of the many alternate forms of comfort indices which have appeared in the literature. However, some such index must be developed, and it is suggested that the index include as parameters all of those time and frequency domain factors which affect the passengers' evaluations of the ride.

2.3.1.3 Transportation Modes as a Basis for Generalizing the Investigation of Ride Quality

The basic emphasis of this current study is on the evaluation of the effect of vibration characteristics of surface transportation vehicles on perceived ride comfort. There are many different vehicles which are being used and which have been proposed for service. Since it is desirable to organize the experiments so that the results can be generalized, we have classified the current and proposed vehicles according to similarities in their suspension and guideway characteristics. The twelve vehicle classes based on these design attributes are referred to as transportation modes. It should be noted that alternate classifications based on performance attributes might also be used as the basis for comparing different vehicles; for instance, buses, rapid rail transit, and automobile (cabs) are all directly competitive for short distance urban trips, and the passenger expectations may be more similar across these modes than between technologically similar vehicles such as urban buses and interurban buses.

The following twelve modal categories may be considered fairly inclusive of present and proposed surface transportation vehicles. The following paragraphs discuss the major factors of similarity within each of the modes. Specific characteristics such as operational factors, habitability factors, passenger demographic factors, vibration characteristics, and the interactions of these factors are summarized in more detail in the following sections.

> Rapid Rail Transit (RRT): Dual rail guideway such as subways and light rail vehicles. Primarily short trip transportation with many stops for passenger access. Major event motions such as starts, stops, and curves which cause passengers to lose balance may be more important determinants of the perceived ride than is the often rough continuous vibration which would cause fatigue on longer trips. Seats are not always available particularly during rush hours, so the ride quality should be evaluated both for standing and seated passengers. The effects of crowding and lack of storage facilities for parcels may also be important factors influencing the quality of the ride.
>
> Interurban Rail (IUR): Conventional passenger trains operating on steel rails, with trip times from one to many hours or even several days. Continuous vibration of the passenger compartment may be due either to guideway irregularities such as rail joints or to onboard equipment. Such vibration may cause passenger fatigue if it is of high amplitude.

Event-type motions due to track crossovers, curves, starts and stops, and changes in track structure may have a high annoyance factor as they may interrupt the passenger's attention to a preferred activity such as sleeping, reading, eating, etc. The distraction potential of unexpected events may make such features of the ride very objectionable to the passengers. Finally, low-frequency roll or lateral vibration due to track hunting or car body sway may result in motion sickness.

Magnetically Levitated Vehicles (MLV): Similar to the interurban train in function and habitability features, but differing from the train because of higher speeds and a softer suspension. Low-frequency pitching, bouncing, or rolling of the passenger compartment may result at certain speeds due to an interaction between periodic guideway geometry features (such as rail joints or suspension piers) and the servo-controlled suspension system. This motion may be more objectionable on an MLV than on a train if the higher speed motion of the landscape seen through the vehicle windows provides less of a stable visual reference to the passengers.

Monorail (MonoR): Similar to either urban or interurban trains, except that lower lateral guidance may result in increased vehicle roll. The guideway foundation of beams between piers will result in a constantly changing support stiffness similar to that experienced by trains on bridges of similar design, resulting in a periodic continuous vertical vibration of low frequency but of a high enough amplitude that it may be objectionable.

Tracked Air Cushion Vehicle (Air Cush (t)): Similar in almost all functional respects to the maglev vehicle. The vibration characteristics of the rides of the air cushion and maglev vehicles should be very similar, with the air cushion vehicle having perhaps a higher inherent noise level and higher level of continuous vibration due to the onboard fans and aerodynamic interactions between the vehicle and the air cushion.

Ground Effect Machine (GEM): Essentially an air cushion vehicle which is not restricted to a fixed guideway. Vehicles of this type are currently in service as dual water/land vehicles. The characteristics of the vibration over water are controlled to a great extent by the waves which are encountered; random motions in all three rotational axes are to be expected. Obscured vision through the windows due to water spray generated by the air cushion may also affect the reliability of the external visual directional references.

Personal Rapid Transit (PTPRT): Proposed for short-haul transportation in an urban environment, similar to an automatic taxi restricted to a fixed guideway. The vibration environment may be expected to be of minor importance in comparison with factors such as ease of access and egress and the perceived safety of an unmanned vehicle. Vibration from the guideway and the vehicle suspension may be expected to be similar to that of larger vehicles having similar technological features, i.e., buses or rapid rail transit.

Dual Mode (DMode): Essentially a bus that can run on rails. Functionally equivalent to a bus that can use reserved express lanes for part of its trip. The vibration environment will be similar to a bus on the roadway portion of the trip, and similar to a rapid rail transit vehicle while on the rail guideway. The dual mode vehicle will be smaller in size and weight then the rapid rail transit vehicle.

Interurban Bus (IUBus): Similar in function to the interurban train, but more restrictive to passenger activities than the train due to its smaller size. The ride of the bus will depend on the smoothness of the pavement. The number and severity of vehicle motions resulting from the driver's interaction with other traffic will also have a major influence on the roughness of the ride.

Urban Bus (UrBus): Similar in design to the interurban bus, only having much more frequent starts and stops. Habitability features will be similar to the rail rapid transit, and ease of entry and exit will be important factors.

Moving Belt Transport (MBelt): Primarily short-trip, high-passenger density, low-speed transportation of standing passengers. Major factors affecting the acceptability of the mode would be the ease of getting on and off the belt without losing balance and the provisions made for storage of parcels during the trip.

Passenger in Private Automobile or Cab (Auto): Inherently a rough ride due to the lightness of the vehicle and the high frequency of operational motions resulting from traffic interactions with other vehicles. Operational factors, such as convenience of scheduling and habitability factors such as privacy may be expected to overwhelm the effects of vibrational factors except where only the vibration is changed, as in the comparison of the rides of two similar automobiles.

2.3.1.4 Expected Vibration Environment for Various Vehicles

The characteristic ride on any ground transportation vehicle arises from guideway irregularities and design motions which are peculiar to the specific technology which is used. Although particular vehicles may have suspension characteristics which modify the basic vibration input to the vehicle, the ride will still be similar to that of the vehicles based on the same technology. In addition, it is probably true that not all types of ride characteristics are important to the ride quality of any single type of vehicle, and that the ride could be adequately described through consideration of a limited number of parameters. These vibration parameters would be associated with important features of the guideway and the vehicle suspension

A classification of ground transportation vehicles on the basis of guideway and suspension characteristics is shown in Table 2-2. The important types of vibration and the principal sources of vibration are shown for each type of vehicle. In addition, the peak jerk and acceleration levels which are commonly experienced in service are shown for each vehicle. It should be noted that the continuous vibration environment is not a major factor for any of the vehicles, since the most severe accelerations are associated with impulsive or smeared-impulsive events. This suggests that the investigation of the relationship between ride

Table 2-2. Nature of Vibration on Eleven Vehicle Types

		Guideway Type				Design Aspects of Ride					On-Board Sources-Machinery						Peak Levels				Most Severe Type of Vibration
		Contact, Steel Wheel & Rail	Contact, Pn. Tire & Pavement	Non-Contact Fabricated	Non-Contact Terrain	Stationary Rollers	Frequent Start-Stop	Frequent Interchange	Frequent Lane/Track Change	Frequent Timing	Propulsion & Gear Train	Compressors	Air Conditioning	Motor Generator Set	Support Generated (flatspot)	Instability Generated	Jerk, 1-6 Hz	Roughness 6-20 Hz (Acceleration)	Harshness >20 Hz Velocity	Sustained Lateral 0-1 Hz (Acceleration)	
Rail Rapid Transit		X					X	X	2	2		X	X	3	3	3	60 ft/sec^3	4.0g	.01 ft/sec	.1g	Start-Stop (Design) Lateral Sway (G'way/Susp)
Interurban High-Speed Rail		X							2	2		3	X	3	3	3	40 ft/sec^3	2.5g	.01 ft/sec	.05g	Vertical (Impulsive) Periodic Roll (G/way/Susp)
Magnetic Levitated Vehicle				X							4			X	X		?	?	?	?	Porpoising Motion (G'way/Susp)
Mono-Rail Rapid Transit	Overhead	X	X				X			2		3	X	3			Probably Comparable to Rail or Pneumatic Tired Vehicles				Vertical (G/way/Susp) Pendulum Sway (G'way AQ/Susp)
	Center	X	X				X			2		3	X	3							Vertical (G'way/Susp)
	Side	X	X				X			2		3	X	3							Roll (G'way/Susp)
Tracked Air Cushion Vehicle				X							4		X	3		3	?	?	?	?	?
Untracked Ground Effect Machine					X		2	2		2	4		3				?	?	?	?	?
Pneumatic Tire PRT			X				2	2	2	2					3	3	?	?	?	?	Start-Stop (Design) Vertical (G'way/Susp)
Dual Mode Vehicle		1	1				2	2		2					3	3	45 ft/sec^3	3.0g	.01 ft/sec		Curve Negotiation (Design) Vertical & Roll (G'way/Susp)
Bus	Interurban		X				2	2	2	2			3				40 ft/sec^3	3.0g	.01 ft/sec		Curve Negotiation (Design) Vertical & Roll (G'way/Susp)
	Intermediate		X				2	2	2	2	3		3				40 ft/sec^3	4.0g	.015 ft/sec		Start-Stop & Curves (Design) Vertical (G'way/Susp)
	Small Urban		X				X	X	X	X	X		3				40 ft/sec^3	4.5g	.02 ft/sec		Start-Stop & Curves (Design) Vibration Harshness (Propulsion)
Moving Belt Vehicle						X	X	X	X	X	X				X		?	?	?	?	Longitudinal (Propulsion) Vertical (G'way/Susp)
Automobile			X				2	2	2	2	2	3			3	3	30 ft/sec^3	3.0g	.02 ft/sec	.15g	Start-Stop (Design) Vertical (G'way/Susp)

NOTES:

X Important Source of Vibration

Important factor with the following qualifications:

1. By definition, will use both guideways.
2. Will be defined by trip purpose and origin.
3. Sometimes.
4. Includes suspension/levitation machinery.

and ride quality must carefully consider the effects of such events. The lack of tractable engineering procedures for characterizing events (as compared to the spectral analysis of continuous vibration) will make this investigation more complex. However, this complexity must not be avoided if the results of the research are to be applicable to the design of ground transportation vehicles.

2.3.1.5 Review of Previous Ride Quality Research

Some 79 studies of ride quality have been received and are listed in the reference bibliography. Most of the literature falls into two categories: studies in simulators or shake tables, and surveys of fare-paying passengers. Table 2-3 shows the number of studies that were reviewed for each vehicle. Undoubtedly, there are many more studies. However, the frequencies tabulated provide a rough index of the amount of attention that has been given to ride quality of the vehicles of interest.

Much can be learned from the literature about passenger evaluations of ride which we call ride quality, although all potential implications are not spelled out. At least four areas are relevant:

1. Simulator studies of ride-ride quality relationships.
2. Studies of ride-ride quality in operational vehicles.
3. Mode choice studies.
4. Segments of knowledge and established principles from social sciences and human factors.

Our review in Appendix I summarizes areas 1 and 2 above. We have reviewed some of the mode choice literature, and from this have structured components of O, i.e., operational factors, and rider response (O_s) to these. These findings are incidental to the purposes of this research. They cannot be completely ignored, however, because of their likely overlap with ride quality evaluations. In addition, we suspect that various reasonably well-

Table 2-3. Number of Studies Reviewed for Each Vehicle

VEHICLE	SYMBOL	NUMBER OF STUDIES CHECKED
Rapid Rail Transit	RRT	4
Interurban Railroad	IUR	14
Magnetic Levitation Vehicle	MLV	1
Monorail	MonoR	2
Air Cushioned (t)(tracked)	--	1
Ground Effect Machine	GEM	2
Pneumatic Tired Personal Rapid Transit	PTPRT	3
Dual Mode	--	2
Interurban bus	IUBus	4
Urban Bus	URBus	9
Moving Belt	MBelt	1
Automobile	Auto	8

established principles from social sciences and human factors--for example, stimulus summation and decay as exemplified in the principle of recency, and stimulus masking--can provide insights. These insights should prove useful in setting forth a strategy for the evaluation of ride quality for some twelve transportation system concepts.

2.3.2 HABITABILITY FACTORS IN GROUND TRANSPORTATION VEHICLES

Habitability factors include those vehicle design components which make the vehicle suitable for occupancy and which enable passengers to engage in desired activities while traveling (i.e., reading, conversation, etc.). To achieve acceptable habitability, control of the vehicle's interior environment is necessary as well as appropriate design of seats, baggage racks, handholds, etc.

The effect of habitability and its components on passenger evaluation of ride comfort and acceptability is of importance to vehicle designers. The basic habitability requirements for each type of vehicle are covered by well-documented design standards for each factor. However, the possibility of interaction between vibrations and habitability factors apparently has not been adequately investigated. Seat design will undoubtedly affect the perceptions of vehicle vibration. Other habitability factors may either mask the effects of vibration or result in changes in the evaluative criteria used to judge the acceptability of the ride. Previous research on habitability factors has been reviewed, and a summary of the relevant findings is included as Appendix II.

2.3.3 OPERATIONAL FACTORS AFFECTING EVALUATION OF THE RIDE

Such factors as vehicle headway and schedules, the cost of the ride, the safety record of the transportation mode, and other factors related to the operation of the vehicle are outside of the control of the design engineer. However, these operational factors may affect a passenger's satisfaction with the vehicle or system, thereby affecting his evaluation of the ride.

A review of the literature involving operational factors is summarized in Appendix III. Perhaps the most important finding is that operational factors often appear to be more important to passengers than do vibration and habitability factors. Careful consideration must therefore be given to operational factors in designing an experiment so that if these non-vibration factors affect the passengers' evaluations of the ride, the experimenter is aware of it.

Passengers' expectations of ride may be an important factor in judgment of ride quality. One would expect (though this has not been demonstrated) that these expectations are related to functional or operational factors as well as to the interaction of guideway and vehicle suspension system. Therefore, classification of transportation modes should, perhaps, be based on both vibration environment and on operational similarities of vehicles as perceived by passengers. An alternate approach would be to classify different transportation modes on the basis of actual, rather than perceived, operational similarities.

2.3.4 RELATIVE IMPORTANCE OF HABITABILITY, OPERATIONAL, AND DEMOGRAPHIC FACTORS

Prior research has indicated some of the many factors which may influence passenger evaluations of ride. Tables 2-4, 2-5, and 2-6 summarize where these various factors have been reported in the literature. Those factors which have been found to be of significant importance are indicated by the symbols "I" and "X".

Table 2-4. Demographic Factors That May Influence Ride Evaluations

	Modes of Transportation											
	RRT	IUR	MLV	MonoR	AirCush(t)	GEM	PTPRT	D.Mode	IUBus	UrBus	M.Belt	Auto
1. <u>Passenger Demography</u> Age	I 57 13 31	75 76 49 8		13	13	58	13 26 24 I	26	13 40 7	5 50 26 I		5 24 40 7 26 57
Sex	13 31	47 48 20 38 44		13	13	58	13 26	26	13 40	5 26 50		5 26 40
Income level	13 I			13	13		13 26	26	13 7 40	29 5 26 56 I		I 5 26 74 7 56 57
Social class sub-class	13			13	13		13 26	26	13	I		5 40 26
Urban/Sub-urban/rural	13			13	13		13 26	26 28	13 40	29 5 26		5 26
Physical Disability							24			26		

* = Reference to Bibliography
I = Important (average)
X = Very Important (average overstudies listed)

Table 2-4. Continued

	Modes of Transportation											
	RRT	IUR	MLV	MonoR	AirCush(t)	GEM	PTPRT	D.Mode	IUBus	UrBus	M.Belt	Auto
2. Trip Purposes/ Acitivities at Destination												
Travel to/from work	13 57 I	76 75 68 I		13	13	58	13 26 24 I	26 68	13 7	5 26 58 68 I		5 26 74 7 59 56 57 68 I
Business travel: inter-urban and intra-urban	13 I	68 I		13	13		13 26	26 68	13 68	5 26 68		5 26 I
Personel Travel required	13	I		13	13		13 26	26	13	26 56		26 74 56 I
Travel to social family activities	13 I			13	13		13		13	56		74 56 I
Recreational travel												74
3. Prior Experience Habit	I	I							I	I		I
Prior experience with mode	13 57	80		15 13	13	58	13 26	26	13 26	13 26 58		26 57
Strength of habit	57 X					58 X						57 X

* = Reference to Bibliography
I = Important (average)
X = Very Important (average overstudies listed)

Table 2-4. Continued

	Modes of Transportation											
	RRT	IUR	MLV	MonoR	AirCush(t)	GEM	PTPRT	D.Mode	IUBus	UrBus	M.Belt	Auto
4. Attitudes, Needs Expectations	X 13 26	X 75 76 68		X 68 13	X 13	X 58	X 13 24	X 26 68	X 68 13 40 26	X 56 26 68		X 68 26 13 59 40 56

* = Reference to Bibliography
I = Important (average)
X = Very Important (average overstudies listed)

Table 2-5. Habitability Factors That May Influence Ride Evaluations

Modes of Transportation

Habitability	RRT	IUR	MLV	MohoR	AirCush(t)	GEM	PTPRT	D.Mode	IUBus	UrBus	M.Belt	Auto
a. Comfort: Response to physical motion dynamics: See Tab. 2-6 for relative importance continuous	42 13	20 47 48 80 81		13	13	58 45	13 24 26	63	7 50	45 50 56		7 21 56 59 77 78 79
event type								63				
b. Adequate physical space: privacy		I					24 26		X 7	X 3 5		X 5 7
leg room		8					26 13		13	26		
c. Perceived safety: collision with other vehicles, fixed objects	32	I 5				58		26	7	I 5 26 59 56		I 5 7 26 59
personal safety	13			13	13		13	26		5		5
d. Attractiveness, style, luxury of the interior							24 26			56 26		26 56
cleanliness	13 I	81 I		13 I	13		13 24 26	26	13	26 I		59
e. Permits desired activities: reading, view, etc.	13 32	20 I 81 62		13	13	58	13		7	13 56 59		
f. Independence of control of vehicle									7	56		7 56
g. Protection from weather	I 13			13	13		I 13 26	26	7	I 5 26 56		I 5 7 26 56 59

* = Reference to Bibliography
I = Important (average)
X = Very Important (average overstudies listed)

Table 2-6. Operational Factors That May Influence Ride Evaluations

	Modes of Transportation											
Operational Attributes of Mode and Ride*	RRT	IUR	MLV	MonoR	AirCush(t)	GEM	PTPRT	D.Mode	IUBus	UrBus	M.Belt	Auto
Modal Trip Time	57	X 75 76 35		68		58			7 40 35	56 5 22 68		5 26 7 57 74 35
a. Accessibility-Terminals for boarding vehicle							26	26	40	56 5 26		26
	13			13	13	58	21 13		13	26		5 26
b. Convenience of schedule to traveler needs		81 68 X					X	26 68 X	7 40 X	56 26 68 X		26 7 X
c. Reliability of arrival time, end of trip	I	81 I					26 I			68 56 I		59 I
d. Time savings versus other modes		68 35 X				58	26 X	26 68 X	7 35 40 X	56 5 26 X		5 26 7 74 I
e. Minimum waiting times, no transfers	13 57 I	68 I		13 I	13 I		26 I	68 I	7	56 5 68 I		5 7 57 I
f. Perceived social class, other passengers	13 32 I	68		13	13		13 26			13 I		
g. Trip cost	13 32 X	68 35 X		13 68	13		13 26 X	26 68 X	35 13 7 X	5 26 56 59 68 X		5 71 7 35 26 57 59 I
h. Seat availability	13	48 X		13	13	58	13			5 X		5

* Based on prior studies, these attitudes are believed important but they do not depend in any direct sense on variables associated with design of vehicle/track/vehicle interior.

I = Important (average)
X = Very Important (average overstudies listed)

2.4 IMPLICATIONS OF PRIOR RIDE QUALITY RESEARCH FOR A MODEL OF RIDE-RIDE QUALITY

The history and the state of the art in the investigation of ride and ride quality have been reviewed and summarized for several purposes. The review helps to define the components or elements of ride and ride quality which have been found important in prior studies. It indicates what methods have been used to measure ride and ride quality and to what success. Areas wherein knowledge is deficient can be identified. Relationships that have been established have been incorporated into the model. Methods which have been used in the past have been evaluated for possible incorporation into the experimental design. Finally, in reviewing literature, we can identify nonproductive lines of inquiry, and, hopefully, means of avoiding them can be identified.

In reviewing this literature, the broader objectives of the present study must be kept in mind. Typically, the literature consists of small studies or experiments, each with limited objectives. The fact that many prior studies do not contribute much to the evaluation of the ride quality of operational vehicles is not a criticism, but rather reflects the far broader objectives of this study.

2.4.1 IMPORTANT VIBRATION FACTORS AND THEIR INTERACTION WITH HABITABILITY FACTORS

The ride of a vehicle has been described in terms of vibration and subcomponents (direction, frequency, repetition, etc.), habitability and subcomponents (noise, seat design, environmental control, etc.), and operational factors such as trip duration. These factors may vary in importance from one type of vehicle to another, and likewise they may interact in important ways. All of the factors and their interactions theoretically should be investigated. However, the criterion of experimental efficiency requires that the most important factors be identified from existing sources and that these factors be investigated first.

A preliminary evaluation of the relative importance of ride factors as defined by V and H, and the major sources of vehicle vibration is summarized in Table 2-7 for each of the transportation modes previously defined. In addition, probable interactions are also noted. This classification and evaluation of stimulus parameters is presented as a guide to the development of experimental designs, although careful consideration of a particular vehicle will often reveal vehicle-specific factors which must also be investigated.

Table 2-7. The Effect of Vibration on Ride Quality and Its Interaction with Other Factors

2-7a. Rail Rapid Transit (RRT)

RELATIVE IMPORTANCE OF FACTOR

	SOURCE OF VIBRATIONS										VIBRATION AXIS						VIBRATION CLASSIFICATION						HABITABILITY					PREFERRED ACTIVITY					
	RANDOM GUIDEWAY	PERIODIC GUIDEWAY	EVENT GUIDEWAY	DESIGN MOTIONS	PROPULSION SYSTEM	VEHICLE SUBSYSTEMS	SUSPENSION	INSTABILITY-GUIDEWAY	VEH. INTERCONNECTION		1. VERTICAL	2. LATERAL	3. LONGITUDINAL	4. YAW	5. PITCH	6. ROLL	7. PERIODIC CONTINUOUS	8. PERIODIC IMPULSIVE	9. PERIODIC SMEARED	10. RANDOM CONTINUOUS	11. RANDOM IMPULSIVE	12. RANDOM SMEARED	13. NOISE - CONTINUOUS	14. NOISE - IMPULSIVE	15. SEATING - CUSHIONING	16. SEATING - SPACING	17. ENVIRONMENTAL CONTROL	18. READING	19. CONVERSATION	20. GROUP ACTIVITIES	21. SLEEPING	22. PRIVACY	23. TRIP DURATION
	X	I	X		I	I	I	I		1	X																						
	X	X		X				X		2	I	X																					
				X	X				X	3	I	I	X																				
		I						I		4		I		I																			
										5																							
		X					I			6		I		I		I																	
		X			I	I			X	7	I			X		X	X																
		I					I			8		I				I		I															
		X								9	X	X		I		X	I		X														
	I					I				10	X	I								I													
			X	I	I					11	X	I	I				I		I		X												
			X	X	X				I	12	X	X	X			I	I		I		I	X											
	I				X	I	X	I		13	I	I	I				X			X			X										
		X	X	I	I		X			14	I							X			X		I	X									
	I	I	I							15	X						X			I					I								
		X		X	X				I	16	X	X	I			X	I			I						X							
										17																	X						
	I	X	X	I	I				X	18	X	X	I			I	I	I		I	X	X	X	I		X		X					
			X		X	I	X			19										I	I		X	X		X			X				
										20													X	I		X				I			
		I	X	X	I		I			21								I			I			X	I	I					I		
										22																							
	I	X	I	X	X	X	I		I	23	I	X	X			I	X	I	I				I	I	I	I	X	I		I	I		I

X = Very Important; I = Probably Important; blank = Probably Unimportant

Table 2-7. The Effect of Vibration on Ride Quality and its Interaction with Other Factors

2-7b. Interurban Train (IUR)

		RELATIVE IMPORTANCE OF FACTOR	RANDOM GUIDEWAY	PERIODIC GUIDEWAY	EVENT GUIDEWAY	DESIGN MOTIONS	PROPULSION SYSTEM	VEHICLE SUBSYSTEMS	SUSPENSION	INSTABILITY-GUIDEWAY	VEH. INTERCON.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
VIBRATION AXIS	1. VERTICAL	X	X	X	I		I	I	X																								
	2. LATERAL	X	I	X	X	I			I	X		I																					
	3. LONGITUDINAL	I				I	I				I	I	I																				
	4. YAW																																
	5. PITCH																																
	6. ROLL	X	I	X	I	X		I	I		I	I	I	I																			
VIBRATION CLASSIFICATION	7. PERIODIC CONTINUOUS	I		I						I	I	I	I	I																			
	8. PERIODIC IMPULSIVE	I		I					X			I																					
	9. PERIODIC SMEARED	X		X								X	I				X																
	10. RANDOM CONTINUOUS	X	X									X	X				X			I													
	11. RANDOM IMPULSIVE	I			I	I					I	X	I	X																			
	12. RANDOM SMEARED	I			I	I					I	I	X	X																			
HABITABILITY	13. NOISE - CONTINUOUS	I					I	X	X		I	I	I	I				I			I												
	14. NOISE - IMPULSIVE	I		X	I			I	I		I	I	I	I					I			I		I									
	15. SEATING - CUSHIONING	X	X	I	I							X	I					I			X												
	16. SEATING - SPACING	X				I	I					X	X				X			X			X										
	17. ENVIRONMENTAL CONTROL	X																															
PREFERRED ACTIVITY	18. READING	X	I	X	X	I	I	I	I	I	X	X	X	X			I	I	X	I	I	I	I	I	I	I	I						
	19. CONVERSATION	I							I		I													I	I								
	20. GROUP ACTIVITIES	X							I															I	I		X	I					
	21. SLEEPING	I	I	I	X	X	I	I	X	I	X	I	X	X			I		X			X	I	X	X	X	X	I					
	22. PRIVACY	I																						I			X		I	I	I	X	
	23. TRIP DURATION	X	I	X	I	I	I	I	I		I	X	X	X			X	I	I	X	X			I		X	I	X			I	I	I

X = Very Important; I = Probably Important; blank = Probably Unimportant

Table 2-7. The Effect of Vibration on Ride Quality and its Interaction with Other Factors

2-7c. Magnetically Levitated Vehicle (MLV)

RELATIVE IMPORTANCE OF FACTOR

SOURCE OF VIBRATIONS										VIBRATION AXIS						VIBRATION CLASSIFICATION						HABITABILITY					PREFERRED ACTIVITY					
RANDOM GUIDEWAY	PERIODIC GUIDEWAY	EVENT GUIDEWAY	DESIGN MOTIONS	PROPULSION SYSTEM	VEHICLE SUBSYSTEMS	SUSPENSION	INSTABILITY-GUIDEWAY	AERO FORCES		1. VERTICAL	2. LATERAL	3. LONGITUDINAL	4. YAW	5. PITCH	6. ROLL	7. PERIODIC CONTINUOUS	8. PERIODIC IMPULSIVE	9. PERIODIC SMEARED	10. RANDOM CONTINUOUS	11. RANDOM IMPULSIVE	12. RANDOM SMEARED	13. NOISE - CONTINUOUS	14. NOISE - IMPULSIVE	15. SEATING - CUSHIONING	16. SEATING - SPACING	17. ENVIRONMENTAL CONTROL	18. READING	19. CONVERSATION	20. GROUP ACTIVITIES	21. SLEEPING	22. PRIVACY	23. TRIP DURATION
I	I	I		X	I	X	I		1	X																						
I	I	I	I	I				I	2		I																					
									3																							
									4																							
	X	I				X	X		5	X				X																		
									6																							
	X			I	I	I			7	X	I			X		X																
									8																							
									9																							
X				I		I			10	X	I			X		I			X													
		X							11	X						I			I	X												
X								I	12	I	I										I											
				X	I	X			13													I										
		X				X			14	X	X									X			I									
									15															I								
									16																X							
									17																	X						
									18																I		X					
									19																			X				
									20																I	I			I			
							I		21					I									I		I	I				I		
									22																							
I	I			X	I	X	I		23	X				X		I			I			I				X	X		I	I		I

X = Very Important; I = Probably Important; blank = Probably Unimportant

Table 2-7. The Effect of Vibration on Ride Quality and Its Interaction with Other Factors

2-7d. Monorail (MonoR)

[Steel wheel on steel rail assumed.]

	SOURCE OF VIBRATIONS									RELATIVE IMPORTANCE OF FACTOR / VIBRATION AXIS						VIBRATION CLASSIFICATION						HABITABILITY					PREFERRED ACTIVITY					
	RANDOM GUIDEWAY	PERIODIC GUIDEWAY	EVENT GUIDEWAY	DESIGN MOTIONS	PROPULSION SYSTEM	VEHICLE SUBSYSTEMS	SUSPENSION	INSTABILITY-GUIDEWAY	AERO FORCES	1. VERTICAL	2. LATERAL	3. LONGITUDINAL	4. YAW	5. PITCH	6. ROLL	7. PERIODIC CONTINUOUS	8. PERIODIC IMPULSIVE	9. PERIODIC SMEARED	10. RANDOM CONTINUOUS	11. RANDOM IMPULSIVE	12. RANDOM SMEARED	13. NOISE - CONTINUOUS	14. NOISE - IMPULSIVE	15. SEATING - CUSHIONING	16. SEATING - SPACING	17. ENVIRONMENTAL CONTROL	18. READING	19. CONVERSATION	20. GROUP ACTIVITIES	21. SLEEPING	22. PRIVACY	23. TRIP DURATION
1	X	I	X		I	I	I			X																						
2	X	X		X			I	I	I	I	X																					
3				X	X					I	I	X																				
4																																
5																																
6		X					I		I	I	I	I			X																	
7		X			I	I				I	I				X	X																
8		I					I			I	I				I		I															
9		X								X	X				X	I		X														
10	I					I				X	I				I				I													
11			X	I	I					X	I	I			I					I												
12			X	X	X				I	X	X	X			I	I		I			X											
13	I				I	I													I			I										
14		I	I	X						I	I						I			I			I									
15	I	I	I							X						X			I					I								
16		X		X	X					X	X	I			X	I			I						X							
17																										X						
18	I	X	X	I	I					X	X	I			I	I	I		I	X	X	X	I		X		X					
19																			I	I		I	I		X			X				
20																						I			X				I			
21																	I			I			I	I	I					I		
22																																
23	I	X	I	X	X	I	I		I	I	I	X			X	X	I	I				I	I	I	I	X	I		I	I		I

X = Very Important; I = Probably Important; blank = Probably Unimportant

Table 2-7. The Effect of Vibration on Ride Quality and Its Interaction with Other Factors

2-7e. Tracked Air Cushion Vehicle

(Air Cush (t))

SOURCE OF VIBRATIONS									RELATIVE IMPORTANCE OF FACTOR	VIBRATION AXIS						VIBRATION CLASSIFICATION						HABITABILITY					PREFERRED ACTIVITY					
RANDOM GUIDEWAY	PERIODIC GUIDEWAY	EVENT GUIDEWAY	DESIGN MOTIONS	PROPULSION SYSTEM	VEHICLE SUBSYSTEMS	SUSPENSION	INSTABILITY-GUIDEWAY	AERO FORCES		1. VERTICAL	2. LATERAL	3. LONGITUDINAL	4. YAW	5. PITCH	6. ROLL	7. PERIODIC CONTINUOUS	8. PERIODIC IMPULSIVE	9. PERIODIC SMEARED	10. RANDOM CONTINUOUS	11. RANDOM IMPULSIVE	12. RANDOM SMEARED	13. NOISE - CONTINUOUS	14. NOISE - IMPULSIVE	15. SEATING - CUSHIONING	16. SEATING - SPACING	17. ENVIRONMENTAL CONTROL	18. READING	19. CONVERSATION	20. GROUP ACTIVITIES	21. SLEEPING	22. PRIVACY	23. TRIP DURATION
I	I	I		X	I	X	I		1	X																						
I	I	I	I	I				I	2		I																					
									3																							
									4																							
	X	I				X	X		5	I				X																		
									6																							
	X		X	I	X				7	X	I			X		X																
									8																							
									9																							
X				X		X			10	X	I			X		I			X													
		X							11	X						I			I	X												
X									12	I	I										I											
				X	I	X			13													X										
		X				X		X	14	X	X												I									
									15															I								
									16																X							
									17																	X						
									18													I			I		X					
									19													I						X				
									20																I				I			
							I		21													X	I		I					I		
									22																							
I	I			X	I	X	I		23	X				X		I			I			X		I		X	X		I	I		I

X = Very Important; I = Probably Important; blank = Probably Unimportant

Table 2-7. The Effect of Vibration on Ride Quality and its Interaction with Other Factors

2.7f. Ground Effect Machine (GEM)

SOURCE OF VIBRATIONS: RANDOM GUIDEWAY	PERIODIC GUIDEWAY	EVENT GUIDEWAY	DESIGN MOTIONS	PROPULSION SYSTEM	VEHICLE SUBSYSTEMS	SUSPENSION	INSTABILITY-GUIDEWAY	AERO FORCES		RELATIVE IMPORTANCE OF FACTOR	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
									VIBRATION AXIS																							
X		I		X		X			1. VERTICAL	X																						
X		I		X		X		X	2. LATERAL	X	I																					
		I	X	X		X			3. LONGITUDINAL	I																						
		I							4. YAW	I	I	I																				
		I							5. PITCH	I	I	I		I																		
X		I						I	6. ROLL	I	I	I		I	I																	
									VIBRATION CLASSIFICATION																							
					X		X		7. PERIODIC CONTINUOUS	X	X	X	X																			
									8. PERIODIC IMPULSIVE																							
									9. PERIODIC SMEARED																							
X				X		X			10. RANDOM CONTINUOUS	X							I															
									11. RANDOM IMPULSIVE																							
		X	X					I	12. RANDOM SMEARED	X							I			I												
									HABITABILITY																							
				X		X			13. NOISE - CONTINUOUS	X	I	I	I				I			I												
									14. NOISE - IMPULSIVE																							
I				X		X			15. SEATING - CUSHIONING	X	X	I	I				X			X		I										
		I	I	I					16. SEATING - SPACING	I		I	I									I										
									17. ENVIRONMENTAL CONTROL	I																						
									PREFERRED ACTIVITY																							
I		I		X		X			18. READING	I	X	X	X			I	X			X			X									
				X		X			19. CONVERSATION	X							X			X			X									
									20. GROUP ACTIVITIES																							
		X		I		I			21. SLEEPING	I	I	I	I										I									
									22. PRIVACY																							
I		I	I	X		X			23. TRIP DURATION	X	X	X	X	I	I	I	X			X			X		X	I	X	X	X		I	

X = Very Important;   I = Probably Important;   blank = Probably Unimportant

Table 2-7. The Effect of Vibration on Ride Quality and Its Interaction with Other Factors

2.7g Personal Rapid Transit (PTPRT)

		SOURCE OF VIBRATIONS																															
		RANDOM GUIDEWAY	PERIODIC GUIDEWAY	EVENT GUIDEWAY	DESIGN MOTIONS	PROPULSION SYSTEM	VEHICLE SUBSYSTEMS	SUSPENSION	INSTABILITY-GUIDEWAY		RELATIVE IMPORTANCE OF FACTOR	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
VIBRATION AXIS	1. VERTICAL	X	I	X			I				X																						
	2. LATERAL	I		I	X		I				X	I																					
	3. LONGITUDINAL				X	X					X	I	I																				
	4. YAW																																
	5. PITCH																																
	6. ROLL	I	I	I	I						I	I	I																				
VIBRATION CLASSIFICATION	7. PERIODIC CONTINUOUS		I			X	I				X	X	I	I																			
	8. PERIODIC IMPULSIVE		I								I																						
	9. PERIODIC SMEARED																																
	10. RANDOM CONTINUOUS	X				I	I				X							I															
	11. RANDOM IMPULSIVE			I		I					I	I																					
	12. RANDOM SMEARED				X	X					X							I			I												
HABITABILITY	13. NOISE - CONTINUOUS					I	I				I																						
	14. NOISE - IMPULSIVE																																
	15. SEATING - CUSHIONING										I	I						I				I											
	16. SEATING - SPACING										X	I	X	X				I					X										
	17. ENVIRONMENTAL CONTROL										I																						
PREFERRED ACTIVITY	18. READING	I		I		X	I				X	X	I	I			I										X						
	19. CONVERSATION										X																I						
	20. GROUP ACTIVITIES										I																						
	21. SLEEPING				I	I					I															I	I						
	22. PRIVACY																																
	23. TRIP DURATION	I	I	I	X	I					I	I	I	I				I			I			I		I	X	I	I	I			

X = Very Important; I = Probably Important; blank = Probably Unimportant

Table 2-7. The Effect of Vibration on Ride Quality and Its Interaction with Other Factors

2-7h. Dual Mode (DMode)

RELATIVE IMPORTANCE OF FACTOR

	SOURCE OF VIBRATIONS								VIBRATION AXIS						VIBRATION CLASSIFICATION						HABITABILITY					PREFERRED ACTIVITY					
	RANDOM GUIDEWAY	PERIODIC GUIDEWAY	EVENT GUIDEWAY	DESIGN MOTIONS	PROPULSION SYSTEM	VEHICLE SUBSYSTEMS	SUSPENSION	INSTABILITY-GUIDEWAY	1. VERTICAL	2. LATERAL	3. LONGITUDINAL	4. YAW	5. PITCH	6. ROLL	7. PERIODIC CONTINUOUS	8. PERIODIC IMPULSIVE	9. PERIODIC SMEARED	10. RANDOM CONTINUOUS	11. RANDOM IMPULSIVE	12. RANDOM SMEARED	13. NOISE - CONTINUOUS	14. NOISE - IMPULSIVE	15. SEATING - CUSHIONING	16. SEATING - SPACING	17. ENVIRONMENTAL CONTROL	18. READING	19. CONVERSATION	20. GROUP ACTIVITIES	21. SLEEPING	22. PRIVACY	23. TRIP DURATION
1	X	I	X		X	I	I	I	X																						
2	I	X	X	X	I	I		I	I	X																					
3				X	X				I	I	X																				
4																															
5																															
6	I	X	I	X					I	I				X																	
7		I			X	I		I	X	I				X	X																
8		X					X		X	X					I	X															
9		X							X	I				X	I	I	X														
10	X				I	I			X	X	I			I	I	I	I	X													
11			X	I	I				X	I	X			I				I	X												
12				X	X				X	X	X			X	I			I		X											
13	I				X	I			I	I	I				I			I			I										
14		I	I	I			I		I							I			I			I									
15	I	I	I						X	I					X			I	I				I								
16		I	X	X	X				X	X	I				I	I		I	I	X				X							
17																									X						
18	I	X	X	X	I				X	X	I			I	I	X	X	I	X	X	I	I	I	X		X					
19					I																I	I		X			X				
20					I																I			X				I			
21			I		I														I			I	I	I					I		
22																															
23	I	X	X	X	X	I			I	X	X			I	X	I	I	I	X	X	I	I	I	I	X	I		I	I		I

X = Very Important; I = Probably Important; blank = Probably Unimportant

Table 2-7. The Effect of Vibration on Ride Quality and Its Interaction with Other Factors

2-7i. Interurban Bus (IUBus)

RELATIVE IMPORTANCE OF FACTOR

	SOURCE OF VIBRATIONS								VIBRATION AXIS					
	RANDOM GUIDEWAY	PERIODIC GUIDEWAY	EVENT GUIDEWAY	DESIGN MOTIONS	PROPULSION SYSTEM	VEHICLE SUBSYSTEMS	SUSPENSION	INSTABILITY-GUIDEWAY	1. VERTICAL	2. LATERAL	3. LONGITUDINAL	4. YAW	5. PITCH	6. ROLL
1	X	I	I		I	I		I	X					
2			I	X					I	X				
3				X	X				I	I	X			
4														
5														
6			I	X					I	I	I			I
7		I			X	I	I	I	X	I				
8		X							I					
9		X							I					
10	X				I				X	I				
11			X	I			I		X		I			
12			X	X	X				I	X	X			I
13					I	I	I		I	I	I			
14														
15	X	I	I						X	I				
16			X	X	X				I	X				X
17														
18	X	I	X	I	I	I			X	X	I			I
19					I									
20				X	X					X	X			
21			X	I					X					
22														
23	I			I	I				X	X	X			X

	VIBRATION CLASSIFICATION								HABITABILITY			PREFERRED ACTIVITY					
	7. PERIODIC CONTINUOUS	8. PERIODIC IMPULSIVE	9. PERIODIC SMEARED	10. RANDOM CONTINUOUS	11. RANDOM IMPULSIVE	12. RANDOM SMEARED	13. NOISE - CONTINUOUS	14. NOISE - IMPULSIVE	15. SEATING - CUSHIONING	16. SEATING - SPACING	17. ENVIRONMENTAL CONTROL	18. READING	19. CONVERSATION	20. GROUP ACTIVITIES	21. SLEEPING	22. PRIVACY	23. TRIP DURATION
1																	
2																	
3																	
4																	
5																	
6																	
7	I																
8		I															
9			I														
10				X													
11				I	X												
12				I	I	X											
13	I			I			I										
14																	
15	I			X	I				X								
16	I	I		I	I	X				X							
17											I						
18	I	X	X	I	X	X			I	I	I	X					
19							I				I		I				
20					I	X				I	X			I			
21					X	I	I		X	X	X				I		
22																	
23	I	I	I	X	I	I	I		X	X	X			I	I		X

X = Very Important; I = Probably Important; blank = Probably Unimportant

Table 2-7. The Effect of Vibration on Ride Quality and Its Interaction with Other Factors

2-7j. Urban Bus (URBus)

SOURCE OF VIBRATIONS											VIBRATION AXIS						VIBRATION CLASSIFICATION						HABITABILITY					PREFERRED ACTIVITY				
RANDOM GUIDEWAY	PERIODIC GUIDEWAY	EVENT GUIDEWAY	DESIGN MOTIONS	PROPULSION SYSTEM	VEHICLE SUBSYSTEMS	SUSPENSION	INSTABILITY-GUIDEWAY	VEHICLE MAINTENANCE		RELATIVE IMPORTANCE OF FACTOR	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
X	I	X		X	I			X	1. VERTICAL	X																						
		X	X	I					2. LATERAL	X	I																					
			X	X					3. LONGITUDINAL	X	I	I																				
									4. YAW																							
									5. PITCH																							
I		X	X						6. ROLL	I	I	I																				
	I			X	I				7. PERIODIC CONTINUOUS	X	X	I	I																			
									8. PERIODIC IMPULSIVE																							
									9. PERIODIC SMEARED																							
X				I					10. RANDOM CONTINUOUS	X	X	I				I	I															
		X				X		X	11. RANDOM IMPULSIVE	I	X					I																
		X	X	X					12. RANDOM SMEARED	X	X	X	X			X	I			I												
I				X	I	I		I	13. NOISE - CONTINUOUS	X	I	I	I				X			X												
		X						X	14. NOISE - IMPULSIVE	I	I										X		I									
I	I	I						I	15. SEATING - CUSHIONING	I	X	I	I				X			X	X	I										
			X	X					16. SEATING - SPACING	X	I	X	X			I	I			I	I	X										
									17. ENVIRONMENTAL CONTROL	X																						
I	I	X	X	I				I	18. READING	X	X	X	I			I	I			I	X	X	X	I	I	X						
				I				I	19. CONVERSATION	X										I	I		I	I		X						
				I				I	20. GROUP ACTIVITIES	I													I			X						
		I		I				I	21. SLEEPING	I											I			I	I	I						
									22. PRIVACY																							
I	I	X	X	X	I			X	23. TRIP DURATION	I	I	I	X			I	X			I	X	X	I	I	I	I	X	I		I	I	

X = Very Important; I = Probably Important; blank = Probably Unimportant

Table 2-7. The Effect of Vibration on Ride Quality and Its Interaction with Other Factors

2-7k. Moving Belt Transport (MBelt)

		SOURCE OF VIBRATIONS									RELATIVE IMPORTANCE OF FACTOR
		RANDOM GUIDEWAY	PERIODIC GUIDEWAY	EVENT GUIDEWAY	DESIGN MOTIONS	PROPULSION SYSTEM	VEHICLE SUBSYSTEMS	SUSPENSION	INSTABILITY-GUIDEWAY	SYSTEM FAILURE	
VIBRATION AXIS	1. VERTICAL	I	I	I				I			I
	2. LATERAL				I						I
	3. LONGITUDINAL				X	I				X	X
	4. YAW										
	5. PITCH										
	6. ROLL										
VIBRATION CLASSIFICATION	7. PERIODIC CONTINUOUS		I			I					I
	8. PERIODIC IMPULSIVE										
	9. PERIODIC SMEARED										
	10. RANDOM CONTINUOUS	I						I			I
	11. RANDOM IMPULSIVE		I								X
	12. RANDOM SMEARED				X					X	X
	13. NOISE - CONTINUOUS										
	14. NOISE - IMPULSIVE										
HABITABILITY	15. SEATING - CUSHIONING										
	16. SEATING - SPACING			I							I
	17. ENVIRONMENTAL CONTROL			X							
PREFERRED ACTIVITY	18. READING										
	19. CONVERSATION										I
	20. GROUP ACTIVITIES										
	21. SLEEPING										
	22. PRIVACY										
	23. TRIP DURATION										

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
1																						
2																						
3																						
4																						
5																						
6																						
7	I																					
8																						
9																						
10	I																					
11	I																					
12		I	X																			
13																						
14																						
15																						
16																						
17																						
18																						
19																I						
20																						
21																						
22																						
23																						

X = Very Important; I = Probably Important; blank = Probably Unimportant

Table 2-7. The Effect of Vibration on Ride Quality and Its Interaction with Other Factors

2-71. Passenger in Private Automobile (Auto)

		SOURCE OF VIBRATIONS																															
		RANDOM GUIDEWAY	PERIODIC GUIDEWAY	EVENT GUIDEWAY	DESIGN MOTIONS	PROPULSION SYSTEM	VEHICLE SUBSYSTEMS	SUSPENSION	INSTABILITY-GUIDEWAY	AERO FORCES		RELATIVE IMPORTANCE OF FACTOR	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
VIBRATION AXIS	1. VERTICAL	X	X	X		I		I	X		1	X																						
	2. LATERAL	I		I	X					X	2	X	I																					
	3. LONGITUDINAL				X	X					3	X	I	I																				
	4. YAW				I					X	4	I		I																				
	5. PITCH		I	X							5	I	I			I																		
	6. ROLL			X	I						6	I				I	I																	
VIBRATION CLASSIFICATION	7. PERIODIC CONTINUOUS		I			X	I	I	X		7	X	X	I			I																	
	8. PERIODIC IMPULSIVE		X					X			8	X	X						I															
	9. PERIODIC SMEARED										9	X	X	I					I	I														
	10. RANDOM CONTINUOUS	X				I	I				10	I	I	I																				
	11. RANDOM IMPULSIVE			X	I						11	X	X	I	I			I	I	I	I													
	12. RANDOM SMEARED			I	X	X				X	12	X	I	X	X	I	I	I	I	I	I		I											
HABITABILITY	13. NOISE - CONTINUOUS	X	I			X	I	X		X	13	X	X	I					X			X												
	14. NOISE - IMPULSIVE		X	X				X			14	X	X	I						X			X											
	15. SEATING - CUSHIONING	X	X	X				I	I		15	X	X	I						I	I		X	I										
	16. SEATING - SPACING			X	X	X		I			16	X	I	X	I			I			I		I	X										
	17. ENVIRONMENTAL CONTROL										17	I																						
PREFERRED ACTIVITY	18. READING	X	X	I					I		18	I	X	I				I	I	I	X	X	I											
	19. CONVERSATION					X	I	I		X	19	X													X	I		I						
	20. GROUP ACTIVITIES				I	I					20	I													I			X						
	21. SLEEPING		I	X	X	X	I	I	X		21	X	X	X	X				I	X		I	X	I	I	X								
	22. PRIVACY										22	X																						
	23. TRIP DURATION	I	X	I	I	X	I		X		23	X	X	I	I				X	I	I	X	I		X	I	X	X	I	X			X	X

X = Very Important;   I = Probably Important;   blank = Probably Unimportant

2.4.2 DISAGREEMENTS AMONG RESULTS FROM STUDIES

Looking at simulator studies--see Hanes (28)--responses to rides as defined by amplitude and frequency differ substantially, at times by as much as a magnitude. The reasons may be many--small samples, non-representative samples, inaccuracies in stimulus measurement, semantic problems in scaling, differences in instructions, differences in procedures, failure to use available psychometric techniques, etc. As a general conclusion, since results of the many studies often disagree from study to study, one could hardly expect to apply them to predict anything else with accuracy. This situation is unacceptable.

Disagreements among study results indicate that the area is complex, and that an approach must consist of more than uncoordinated individual experiments. A research strategy must tie experiments and results together. Disparate results also suggest that important factors may be operative that are not being taken into account. Finally, disagreements suggest a need to look into problems of research methods and measurements. Concepts we suspect are needed are treated next under the heading of psychological and social factors. Problems of measurement are also discussed.

2.4.3 TREATMENT OF PSYCHOLOGICAL AND SOCIAL FACTORS

More attention needs to be given to the influence of psychological and social factors than we find in the literature. First, such factors need to be introduced into the ride-ride quality model. Thus, the way in which factors such as need, expectation, and habit influence rider-evaluators and evaluations of ride can be systematically studied.

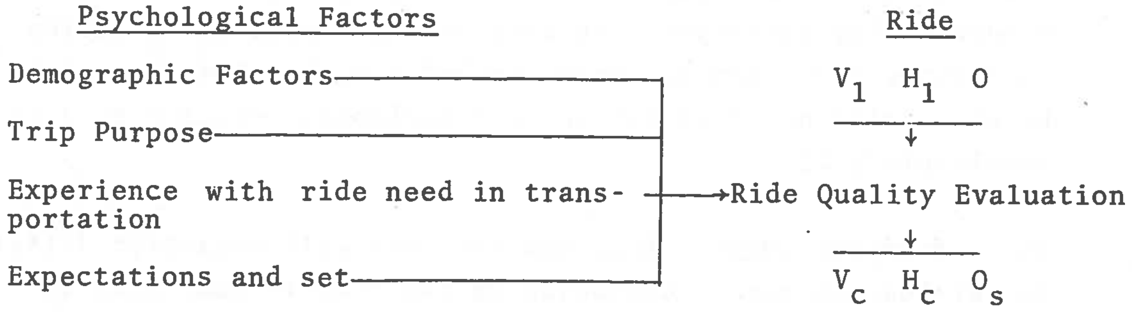
2.4.3.1 Psychological and Social Factors to be Incorporated into the Model

Background psychological and social factors (Table 2-8) that do or may influence judgments of ride quality are classified into five categories:

1. Demographic factors, including income, social class, and age of passengers.
2. Trip purpose.
3. Prior experience with the transportation modes.
4. Needs in transportation.
5. Set and expectations of ride.

Findings from the literature on these factors are reported in Appendix IV. They can be readily combined with elements of the model shown earlier.

Table 2-8. Psychological Factors, Ride and Ride Quality Evaluation



Measurements of psychological factors will permit assessment of their contributions to ride quality evaluations. Further, by establishing correlations between these factors and ride quality evaluations, we can statistically partition out their influence. This, in turn, will permit relationships between V, H, O and sub-components and passenger evaluations of stimulus factors, i.e., V_c, H_c, and O_s to be more precisely established.

2.4.3.2 Need for Further Information with Regard to Psychological Factors

A number of concepts from psychology and human factors suggest important areas to be studied. Among concepts which must be included in a comprehensive model, and which need further study, are the following.

Set, Expectations and Type of Vehicle. We have discussed earlier how needs and the current state of technology help to shape the set and expectations which passengers apply to evaluate ride. The literature also indicates that expectations differ as between driver and passengers, and as a function of the vehicle ridden, whether simulator or operational vehicle.

Evaluations of ride quality in aircraft and private automobile show that pilots and drivers evaluate ride quality more highly than do their passengers (24,39). There is also suggestive evidence that passengers are much more tolerant of vibrations in private cars than in trains or buses (22). Riders tend to be more tolerant of vibration in operational vehicles than in simulators (62).

These findings suggest that subjects may well establish different evaluation norms, depending on the vehicle they plan to ride (or are riding). If this is true, ride quality evaluations as outputs will reflect not only V and H factors, but also different norms that riders apply. This area obviously requires further investigation.

Integration of Experience. The human seems an imperfect and somewhat erratic integrator of past experience. Areas to be developed include:

1. Influence of primacy on evaluative criteria. The very early part of a ride may determine the evaluative criteria used throughout the ride. A bad initial experience may sour the passengers' expectations; a good start may establish a congenial mood.

2. <u>Influence of recency on global evaluations</u>. Evaluations of ride should be more influenced by experience toward the end of the ride than the experience in the middle of the ride.

3. <u>Response to event or spike</u>. In most rides, events or spikes are overlaid on a continuous oscillation environment. How do these events combine with oscillation in the minds of passengers? We would expect that the (negative) influence of spike on evaluations would be proportional to its size and duration. Especially rough spikes may serve as "anchor points" in memory, overriding both primacy and recency effects.

<u>Attention, Preferred Activity</u>. Passengers engaged in reading or conversation may pay little attention to V and H factors unless they are sufficiently rough to interfere with their activities. How rough they must be to interfere with which activities can be determined experimentally.

<u>Habit and Accommodation</u>. By frequent rides on one transportation mode, passengers accommodate developing habits that become well ingrained. We would like to better establish V, H, and O parameters to which riders can readily become accustomed.

2.4.3.3 Conclusions

The concepts described above bear importantly on the planning of ride quality research. Most simulator studies have taken subjects as black boxes and measured their responses to various amplitude-frequency combinations. Factors such as trip purpose, needs, expectations, set, etc., are cancelled out by instructions or not studied. As we go from the simulator to operational rides, means must be provided for measurement of these factors. Otherwise, the effect of these factors on the perception of ride quality may well cancel out relationships established by precise experiments conducted in simulators.

2.5 GENERAL MODEL OF RIDE-RIDE QUALITY

2.5.1 EVALUATIONS OF RIDE QUALITY

The investigation of ride quality can be based on a number of different types of judgment which run the spectrum from ability to discriminate to the assignment of values to rides by passengers. The following classes of responses to rides can help interpret the results of previous research and help plan future experiments.

> Discrimination: The ability of subjefts to discriminate differences in amplitude and frequency has been investigated using standard techniques of psychophysics. Discrimination often appears in the literature in terms of limens or thresholds. Discriminations can result in rank ordering of different rides in order of roughness, or the establishment of interval or ratio scales of perceived intensity of the vibration environment. The current status of this psychophysical, or value free, approach to the investigation of ride quality has been ably reviewed in a recent article by McCullough and Clarke (43).
>
> Comfort: The comfort of a ride depends on the subject's integration of his responses to vibration and habitability parameters, evaluated against some subjective norm of comfort. To the extent to which passengers differ in their sensitivity to different types of vibration, one might expect disagreements as to the relative comfort of similar rides. However, over relatively large excursions of vibration amplitude, passengers should be able to order different rides in terms of comfort.
>
> Acceptability: Whether a particular ride is acceptable to the passengers depends not only on the relative comfort of the ride, but also on whether the ride meets the passengers' expectations.
>
> A passenger will judge the acceptability of a ride on the basis of some preconceived notion of what the ride should be. This expectation may be based on previous experiences with vehicles which are similar either in technological features (same transportation mode) or functional features. In addition, sex, age, and other demographic factors may have an effect on the criteria of acceptability.
>
> For purposes of the investigation of ride quality, it is not important that we can explain why people differ in their requirements of acceptability. Rather, we must note that

people are different and their acceptance of a given vibration environment may be a function of specific habitability, operational, and demographic factors.

2.5.2 RELATIONSHIP BETWEEN PERCEIVED COMFORT AND ACCEPTABILITY

In establishing a design specification, transportation specialists will select somewhat arbitrary points which may be taken as a percentile of the distribution of perceived acceptability, i.e., this ride is found acceptable by some percentage of riders. For instance, a target criterion of ride acceptability in 90 to 95 percent of passengers may be a design goal.

This suggests that the concepts of comfort and acceptability are significantly different. Whether a ride is comfortable is a relative sort of judgment, and judgments of relative comfort can be used to evaluate the differences or similarities between rides of dissimilar vibrational characteristics. Acceptability is made in terms of an absolute judgment as to whether a particular quality of ride (in terms of comfort) meets the minimum expectations or requirements of the passenger. The relationship between comfort and acceptability may be summarized as a functional relationship between orthogonal axes which scale these properties, as is shown in Figure 2-2.

The relationship shown in Figure 2-2 can be directly related to the engineering criteria of specifying the percentage of passengers who will find the ride to be acceptable. In addition, the slope of the transition line between acceptable and unacceptable provides a measure of sensitivity of acceptability judgments to changes in perceived comfort. The fact that there is not a sharp break between "acceptable" and "unacceptable" rides derives from the differences among passengers. This concept of the elasticity of acceptability with respect to perceived comfort must form the basis for any cost/benefit analysis of changes to the ride.

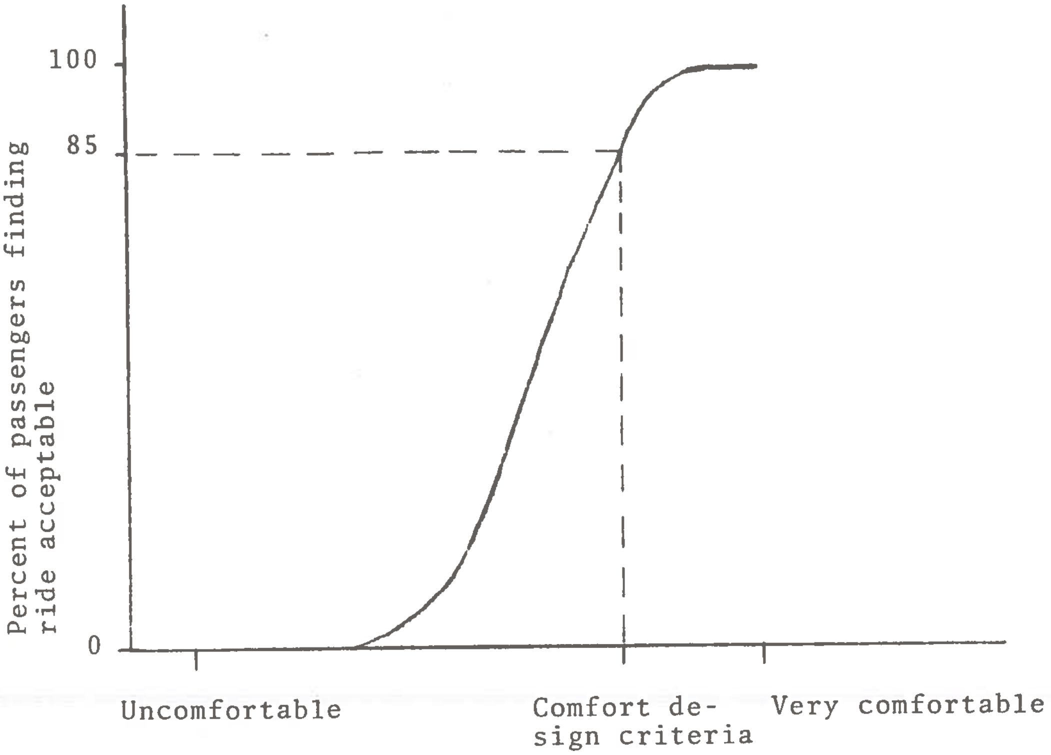


Figure 2-2. Relationship between Perceived Comfort and Acceptability

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2.5.3 LIMITATIONS OF EVALUATIONS OF COMFORT AND ACCEPTABILITY

Two concepts--the zone of indifference and the criteria of acceptability--help to explain anomalies in reported literature, as well as to suggest cutoff points for improved design.

2.5.3.1 The Zone of Indifference

The objective of this report is to present plans for collection of data on passenger response--data to be used as guidance for vehicle design. Neglecting for a moment costs and feasibility, we can visualize situations by which V, H, and O factors are continuously improved to increase the comfort of the ride. Following this progression, some point will eventually be reached--perhaps in some cases has been reached--wherein further improvements in V, H, and O factors do not cause passengers to judge the ride as more acceptable. Thus, by successive improvements, designers have reached what for passengers is subjectively a zone of indifference.

Similarly, small changes in the vibration environment may not affect the perceived comfort even though the change is noticeable to the passenger. A zone of indifference is defined as the amount of excursion of the stimulus along a parameter which evokes no (significant) change in passenger response. The concept provides a design goal. To improve ride quality, vehicle design approaches--but does not quite attain--the zone of indifference of acceptability for a representative sample of passengers. The concept applied to preferences also helps to account for anomalies in a number of studies such as a recent study by Dempsey and Leatherwood (19) which found a "reversal" in ride quality evaluations between .05g and .10g acceleration.

2.5.3.2 Criteria of Acceptability

We have previously used the concept of acceptability as if it were firmly defined. This is in the tradition of previous research into ride quality, as most studies have assumed an implicit definition of acceptability, and have not attempted to define what is meant by the term. No serious problems would result if all of the implicit definitions were the same, but acceptability can be defined in a number of ways which may be mutually exclusive, and confusion as to which of the definitions was used in any particular study limits the comparability of results between different studies.

Without trying to be exhaustive, but to demonstrate that different criteria of acceptability are possible, we propose the following classifications of the acceptability of the ride of a vehicle:

> Behavioral Acceptability: A ride is acceptable if it does not cause a passenger to avoid riding again. This can be determined by observation of passenger behavior.
>
> Internalized Acceptability: A ride is acceptable if it meets or exceeds the internalized "standard" or expectation of acceptability that the passenger held when he started the ride. This can be determined by asking the passenger (assuming that you get an honest response), but has only limited use in terms of a cost/benefit analysis of ride improvements.
>
> Political Acceptability: A ride is acceptable if the passenger does not complain to someone who can influence the vehicle designer or operator. The criteria here is not whether the passengers like the ride but whether they dislike it to the point of complaining.

Other definitions are also possible, each having a place on the hierarchy of degrees of acceptability, and each having a greater or lesser relevance to cost/benefit analyses. The important concept is that any investigation of the acceptability of ride quality must start with an explicit definition of acceptability so that the implications of the experimental results can be properly applied to design and operational decisions.

2.5.4 QUANTIFICATION OF THE RIDE-RIDE QUALITY RELATIONSHIPS

The requirement to relate ride to ride quality as precisely as possible brings in many problems of measurement. These problems exist in abundance both on the stimulus and the response sides of the ride-ride quality equation. On the stimulus side, the physical parameters that define ride elements can be readily defined and measured. Within the vibration environment, however, there are many ways of integrating stimulus measures. Questions arise, however, as to what method of integration is best.

Psychometric techniques can be employed to measure passenger response to vibration and habitation environments. In addition, we need to understand the subjective "mixmaster" by which passengers integrate their impressions to evaluate comfort, acceptability, and whether or not they will continue to use that particular vehicle or transportation concept. There are, then, very substantial problems of measurement and integration, on both sides of the equation. Engineering expertise can be applied on the stimulus side; psychometric techniques can be applied to measure passenger response, to determine the weights passengers give to various elements of the stimulus environment, and to correlate evaluations of ride quality with measures of ride.

The ride-ride quality relationships need to be established by varying ride in known amounts and concurrently measuring the responses of passengers. If we accept the perceived ride quality as the "final arbiter," it provides a way of evaluating the various approaches to calculating numerical descriptors of ride--an especially difficult problem in describing vibration where concepts such as power spectral density and absorbed power have been used. The indices describing vehicle movement which best predict the relative perceived comfort of different vehicles would be the best practicable means of evaluating rides of existing vehicle. In addition, such indices might be used to forecast passenger response to rides in prototype vehicles or those on the drawing board if appropriate equations of motion could be provided.

3. GENERAL EXPERIMENTAL STRATEGY FOR THE INVESTIGATION OF RIDE QUALITY

The model of ride-ride quality relationships provides a basis for planning research studies. Studies should be planned such that results obtained from successive experiments are comparable. Thus, a growing data bank is acquired so that results of each experiment contributes to and broadens our understanding of ride-ride quality relationships.

This planning we refer to as a research strategy. Three major topics to be developed in the formulation of the strategy are: settings for collection of data; measurement of ride and ride quality; and the order in which experimental designs can most efficiently be implemented.

3.1 SETTINGS FOR COLLECTION OF EMPIRICAL DATA

3.1.1 MULTIPLE SETTINGS TO PROVIDE VALIDITY/CONTROL

Our earlier discussions and Appendixes A, B, and C document the complexity of ride-ride quality relationships and the many factors involved. An approach designed to investigate these relationships must meet two criteria. It must assure that data are valid in that they reflect responses of revenue passengers. Second, data collection efforts must permit control so that the many factors that do or may influence ride-ride quality relationships can be introduced singly and in planned combinations.

No single setting can completely satisfy these requirements. Therefore, three settings are recommended. These settings are complementary with respect to the requirement for real-world validity of data and control.

1. Operational rides by fare-paying passengers. These settings assure real-world validity of responses; in effect, each rider uses his own evaluative criteria. Very little control is possible.

2. Operational rides by paid subjects. Since these subjects are riders aboard operational vehicles, we would expect their ratings of ride quality to exhibit some validity in terms of the ratings of rides by revenue passengers. Further, substantial controls can be exercised by selecting coaches and preselecting guideways and roads, by seating subjects at different positions in the coach, and by changing seating arrangements according to pre-established schedules, and by having subjects make repeated evaluations. Controls can also be exercised over demographic parameters by selection of subjects.

3. Rides in simulators. Simulators provide excellent control over vibration parameters which can be varied incrementally in amplitude and frequency. The validity of results in forecasting responses of revenue passengers remains to be tested. Demography can be controlled by selection of subjects.

Taken together, these settings provide valid data as well as controls. All three settings are needed.

3.1.2 SETTINGS AND INTRODUCTION OF V, H AND O

The three settings also provide a systematic means for introduction and study of the influence of vibration, habitability factors and operational factors. The influence of vibration may be studied in the simulator. The combined influence of vibration and habitability factors can be studied in captive passenger experiments. Surveys of revenue passengers introduce the influence of V, H and O.

Table 3-1 compares settings with regard to validity and control. Table 3-2 summarizes advantages and disadvantages of the three settings in greater detail.

3.2 MEASUREMENT TECHNIQUES

It is worth emphasis that quantitative measures of both stimulus and response are needed in each setting to enable us to relate ride to ride quality.

Ride and ride quality factors that can be measured in each setting are shown in Table 3-3. Appendixes A, B, and C, indicate subcomponents of V, H and O that can be measured.

3.2.1 METHODS OF MEASUREMENT

A number of methods are available for measurement of passenger response. While all applications of methods and techniques have not been explored, the following areas should be examined:

1. Discrimination preferences in simulators. (Investigation of possible zones of indifference and the calibration of rating scales.)

2. Rating scales. Scales using techniques developed by Thurstone, Osgood and Likert should apply to evaluations of V, H and their subcomponents.

3. Multidimensional scaling is appropriate for exploring and structuring unknown stimulus or value syndromes.

4. Cross-modality measurement of preferences and perceived ride quality can help develop terminology for rating scales, and will provide a reliability check on scales applied across settings and modes.

5. Questions can be structured to permit subjects to compare V, H and O directly by requesting trade-off decisions.

Table 3-1. Settings for the Examination of Ride-Ride Quality

Settings	Validity of Subject Response	Factors Introduced	Control of Stimulus Factors	Subject Control
Operational Rides Fare-Paying Passengers	Perfect	V_{H_O}	Poor	None
Operational Rides Captive Passengers	Fair	V_H	Fair	Some
Simulator*	To be determined	V	Excellent	Good

* The most flexible: A simulator can approximate any vehicle.

Table 3-2a. Experimental Advantages and Limitations of Three Available Settings

Settings	Vibration Environment		Interior Design for Habitability
I. Operational passengers. Inherently valid; least control.	v = an oscillation on one or more axes definable by acceleration and hertz.	Other movements (i.e., spike, etc.) produced by guideway, pilot (driver) operation.	Can measure for vehicle ridden. Cannot systematically vary. Can compare passenger responses with responses to vibration environment for that ride.
	v and other vibration characteristics associated with operational vehicle/guideway. Cannot vary stimulus parameters in a predetermined way. Can measure v concurrent with ride within capabilities of measurement/recording device.		
II. Captive (or paid) passengers riding in operational vehicles. Next most valid setting, better control of certain stimulus conditions.	Assuming control of route of vehicle, can repeat guideway conditions. By moving subjects about, can measure impact of v at any part of vehicle. Can measure influence of other factors characteristic of dynamic movement of vehicle,i.e., turns, jerk, spikes associated with guideway, etc., to the extent they can be introduced by selection of vehicle guideway as determined by vehicle route.		Can measure for vehicle ridden. Cannot systematically vary. Can compare passenger response to DH_c with response to DV_c for that ride. Because subjects are captive, validity of results needs to be checked against those obtained in Setting I.
III. Simulator studies. Excellent control of stimulus parameters but within capabilities of simulator. Questions as to validity of findings when extrapolated to operational rides	Can systematically explore impact of frequency acceleration, axis, combinations of v on subject ratings.	Some spike effects can be simulated. Cannot simulate jerk, g forces associated with turn in fixed platform simulators.	Can vary systematically influence of factors such as temperature, noise, etc. within capabilities of simulator. Can, in concept, vary seat design and interaction between seat design and v.

Note subscripts: DV_c = Design of vibration environment for comfort; DH_c = Design of habitability environment for comfort; O_s = Satisfaction with operation of vehicle.

Table 3-2b. Experimental Advantages and Limitations of Three Available Settings (continued)

Settings	Influence of Operational Factors	Subjects
I. Operational passengers	Can measure for that vehicle, ride. Can compare influence of operational factors with influence of vibration, habitability environments. Can evaluate tradeoffs between O_s, DV_c, DH_c. Can evaluate impact of social factors, crowding.	Provides valid sample of operational subjects. Can measure influence of demography, set, trip purpose on ride evaluation by passengers
II. Captive (or paid) passengers riding in operational vehicles.	Because subjects are directed and paid, difficult to establish valid measures of influence of operational factors.	Paid subjects. Difficult to determine to what extent samples are representative of the population of riders of public transportation systems. The fact that subjects are paid rather than fare-paying may influence their evaluations of DV_c, DH_c.
III. Simulator studies.	Cannot validly evaluate influence of operational factors, their interactions with evaluations of DV_c, DH_c.	Paid subjects. Difficult to determine to what extent samples are representative of the population of riders of public transportation systems. The fact that subjects are paid rather than fare-paying may influence their evaluations of DV_c, DH_c.

Note subscripts: DV_c = Design of vibration environment for comfort; DH_c = Design of habitability environment for comfort; O_s = Satisfaction with operation of vehicle.

Table 3-2c. Experimental Advantages and Limitations of Three Available Settings (concluded)

Settings	Means of Measurement	Repeatability, Reliability Checks, Statistical Analyses
I. Operational passengers.	Stimulus. Stimulus measured by recording devices, as ride progresses. Limitations are those of measurement device. Subjects. Attitude type measures appropriate, i.e., techniques developed by Thurstone, Likert, Osgood and modifications thereof. Limited ability to obtain repeat measurements.	Can measure inter-subject variations in evaluations. Very limited ability to measure intra-subject reliabilities of ratings. Can obtain relationships within parameters that characterize that ride, those subjects: cannot readily generalize results to other vehicles. Difficult to measure clearly impact of specific ride segments.
II. Captive (or paid) passengers riding in operational vehicles.	Stimulus. Stimulus measured by recording devices, as ride progresses. Limitations are those of measurement device. Subjects. Attitude type measures appropriate, i.e., techniques developed by Thurstone, Likert, Osgood and modifications thereof. Limited ability to obtain repeat measurements.	Rides can be repeated over the same guideway, and repeated ratings used to evaluate DV_c, DH_c, and their components. Intra-subject and inter-subject reliabilites obtainable, subject to questions of validity inherent in using paid passengers.
III. Simulator studies.	Stimulus. Can measure and control stimulus, adjusting duration of presentation(s). Subjects. Can use all instruments in Settings II, III above. Can obtain controlled measures of discrimination, preferences avoiding certain semantic problems inherent in scaling.	By far the best setting for obtaining intra- and inter-subject variabilities in judgments. Stimuli and their interactions can be systematically varied and variances measured repeatedly. Can measure discrimination and preference thresholds.

Note subscripts: DV_c = Design of vibration environment for comfort; DH_c = Design of habitability environment for comfort; O_s = Satisfaction with operation of vehicle.

Table 3-3. Measurement of Response by Settings

	Simulator	Captive Passengers	Operational (Fare-Paying) Passengers
Factors to Measure	V, Some H Factors	V, H V + H	V, H, O V + H + O Expectations
Measurements Approaches	Discrimination Preferences Comfort Ratings Ride Descriptors	Comfort Ratings (f)V, H and V+H Ride Descriptors	Ride Quality, Acceptability (f) comfort, operational factors, expectations

6. Open-ended questions can serve:

   a. To identify terms which people find easy to use in describing various characteristics of ride.

   b. To collect information which by content analysis can suggest expectations for modes.

See Table 3-3 for a summary of factors to be measured.

3.2.2 PROBLEMS OF MEASUREMENT

Three shortcomings in methods and techniques of measurement characteristic of most ride quality studies are worthy of special mention. They must be avoided in experimental designs to be developed.

3.2.2.1 Failure to Establish Reliability Measures

Most prior studies, both with simulators and in the operational context, did not measure reliability of evaluations of ride quality. They did not repeat the stimulus condition so that subjects could evaluate again, thus providing a measure of consistency. Knowledge of intra- and inter-subject variance in evaluations is needed in order to better estimate sample size for future studies, in order to establish standards for selection of samples of subjects, and in order to forecast the distribution of passenger responses to be expected when design criteria are implemented.

3.2.2.2 Measurement of Psychological Response

Many studies of ride quality in simulators have combined discriminations, preferences and evaluations of ride in one scale. This may have satisfied the limited objectives of studies reported. It does not, we think, provide the broad base of knowledge needed as a point of departure for studies of ride in a dozen or more vehicles. At least in the beginning, it is recommended that separate and independent measures be made of discrimination thresholds, preference thresholds, and (absolute) evaluations of ride by subjects.

It is important to determine the discrimination threshold; any design change in a vehicle which does not produce a difference in ride that passengers can discriminate cannot improve ride quality evaluations. But the fact that the passenger can discriminate between two levels of vibration, or two levels of H factors, does not mean he prefers one to the other. Comparisons of discrimination and preference thresholds can potentially yield information of much value. The zone of indifference was described earlier. The fraction

$$\frac{\text{preference threshold}}{\text{discrimination threshold}}$$

provides a quantitative measure of zones of indifference.

Established preference thresholds may be used in still another way; i.e., to verify scales that provide absolute measures of ride quality. The same terms used in rating scales may have different meanings to different people. To avoid these semantic problems, subjects in simulators can be presented with paired stimuli to measure preferences. Measured preferences can then be used to verify absolute scales.

3.2.2.3 The Need to Measure Both Stimulus and Response in Operational Rides

Simulator studies vary acceleration and frequencies in known amounts and measure passenger response in ride evaluations. Most surveys of passenger responses in operational vehicles have not provided quantitative measures of components of V and H. Table 3-4 is a summary of those factors which were reported by various studies for each of the modes of transportation. If we

Table 3-4. Investigation of Stimulus (Design Factor) and/or Response (Passenger Perception) by Study

	RRT	IUr R	AirCush	PT PRT	IUrBus	UrBus	Auto	MonoR	MLV	GEM	Dual Mode	Moving Belt
Vehicle Vibration	7,57 x	7,81 x x 62,80 x	45,58 x	26 x	x 50 x	5,7,26, 36,45,61 x	5,7,26 x x 21,79 x 78 x		x 82	x 58 x	37,63 x	
Starting and Stopping Accelerations	x 12	38 x 20,42,47, 48,49,75, 76 x x		83 x	x 50 x	x 42 x 45,61 x	84 x x 21,77,78 x				63 x	x 6
Noise	57 x	81 x x 62,80 x	13,58 x x 45 x	13,24,26 x		26,61 x x 45 x		19 x		x 58 x	37 x	
Seat	13,57 x	x 8,80,82 x 42,62,75 x	13,45,58 x	13,24 x	13 x	x 42,61 x 5,45 x	5,26 x	13 x			37 x	
Window	13,57 x	62,81 x	45 x		13 x	45 x						
Interior Lighting	13,57 x	81 x		24 x	13 x	x 61 x 26 x					37 x	
Decor	57 x	81 x		24 x		29,59 x x 61 x	29,59 x x 26 x					
Temperature	57 x	81 x	45,58 x	24,26 x		61 x x 45 x					37 x	
Air Quality	13 x	81 x	45,58 x	26 x		26,45,61 x					37 x	
Baggage Accommodations	13 x	81 x	13 x	13,24 x	13 x	29,59 x	29,59 x	13 x				
Entrance/Exit			13 x	24 x		5 x	5 x					x 6
Handholds	13,57 x x 31	42,75,81 x	58 x	13,24 x	13 x		26 x					x 6
Toilet Facilities		81 x	58 x									

Note: Numbers refer to references in the bibliography.

x_____ Measured the stimulus, not passenger response.

_____x Measured passenger response, not the stimulus.

x___x Measured both.

are to relate ride to ride quality in operational vehicles, quantitative measures are needed of both.

3.2.2.4 Ride-Ride Quality Relationships as Relative

In establishing ride-ride quality relationships, one must be keenly aware that he is operating in a relativistic world. In studies of ride-ride quality relationships, correlations established in one context may be greatly different, or non-existent in another. A major objective of experimental design planning must necessarily be to determine how relationships change with changes in setting, stimuli present and psychological and social factors. We suspect that differences in setting are one reason the results of literature studies disagree.

A specific example--only one of many--rises in stimulus masking. A stronger stimulus masks the impact of a weaker one so that the weaker stimulus is not noticed, or if it is, is not responded to by subjects. Thus, a high acceleration jerk would likely mask subject response to continuing oscillations. Or, a high amplitude oscillation in the vertical axis might prevent lower amplitude oscillations on the lateral and longitudinal axes from being perceived.

This masking phenomenon, we expect, occurs not only within the vibration environment, but across into habitability factors and operational factors as well. If a coach is too hot or too cold, subjects would surely respond not primarily to the vibration environment, but to the temperature. The practical meaning of these masking effects and couplings is that both the physical stimulus factors which may influence ride-ride quality relationships and the responses to each factor should be measured.

3.3 ESTABLISHING SETS OF EXPERIMENTAL DESIGNS; ORDERING DESIGNS

Two problems are to be considered--first the design of individual experiments and second, the planning of sets of experiments so that results of several experiments may be related to one another. Results may be compared for a single vehicle, and between vehicles.

For a particular vehicle, we wish to compare results in the three settings--as our charts are arranged, vertical matching. A second form of matching involves using ride-ride quality indices and correlations in one vehicle to forecast indices and correlations in <u>other</u> vehicles; i.e., "horizontal" comparisons. Research design prototypes are described in Chapter 4. Below we describe a procedure for developing designs so that results obtained from designs can be compared.

3.3.1 SIMULATOR WORK

Simulator studies would provide information on the influence of vibration on ride quality ratings across the excursions of types of vibrations that occur in that vehicle type. Then, special studies might investigate the influence of masking among vibration parameters and responses to spikes or events in an oscillation environment.

3.3.2 CAPTIVE PASSENGERS

An experiment in this setting would start with a sample of 16 or 32 captive passengers riding the operational vehicle. This provides an early appreciation of influences of the operational environment. The following procedure is recommended:

1. Identify V and H subcomponents peculiar to the vehicle to be studied.

2. Select guideway, suspension system and specific vehicles for pretest, varying these factors across the operational envelope for the particular transportation mode.

3. Develop scales and instructions for measurement of passenger evaluation of comfort and acceptability.

4. Arrange for measurement of V and H stimuli.

5. Conduct experiment varying ride stimuli systematically. Collect demographic data on subjects.

6. Analyze data, noting any needs for modifications in instructions and rating forms. Develop a data analysis program for responses of fare-paying passengers. Develop an index of relative comfort which relates physical measurements of vibration factors to the perceived comfort of the ride. This relationship can be used to extrapolate the data to other rides by predicting the relative comfort of the rides from estimates of their vibration characteristics.

7. Repeat if necessary to solve any problems in measurement of stimuli and subject responses encountered in the initial experiment. Rating scales and the timing of administration of the ratings may need further refinement.

8. If special problems arise that need study in the simulator, design studies and conduct them.

9. Use ride-ride quality relationships established as a first approximation forecast of ride quality evaluations of fare-paying passengers.

3.3.3 FARE-PAYING PASSENGERS

The procedures and means of measurement of ride and ride quality described above for captive passengers are applied to measure responses of fare-paying passengers. The only addition consists of rating scales for evaluating the influence of operational factors. Data are collected, ride evaluations are obtained and the relationship of relative ride comfort to ride acceptability is established for a particular transportation mode under a limited set of operational and habitability factors.

The detailed design of the experiment must be based on a careful consideration of the use that will be made of the results. The required accuracy of the results must be based on a consideration of the probable cost of error versus the cost of obtaining improved accuracy. The following factors must be considered in this analysis:

1. <u>Definition of acceptable ride</u>. This definition must have economic meaning in terms of passenger utilization of the vehicle or in terms of trade-off between comfort and other factors such as fare or travel time. The most simple definition would be a measure of acceptability as a function of passenger avoidance of the ride, i.e., an unacceptable ride is one which causes the passenger to avoid riding again. This definition creates sampling problems, as the population of fare-paying passengers has already been biased by the voluntary boycott of the vehicle by that portion of its potential ridership who have previously found the ride to be objectionable. Acceptability might also be based on the passengers' expectations and internalized evaluative criteria. The passenger is asked how he likes the ride. Unfortunately, this definition does not relate directly to any economic considerations of the value of degrees of acceptability. Evaluations using this approach are not applicable to the establishment of a ride quality criterion which allows for rational cost/benefit analyses of factors which affect the ride. Realistically, this definition may be the only one that can be applied to subjects in simulator and captive passenger settings. Information of acceptability obtained in these settings will have to be validated in the context of revenue passengers, and the results may have to be adjusted to compensate for operational factors.

   Ideally, the definition of ride acceptability should be based solidly on economic considerations such as the marginal value to the passenger of a perfect ride rather than the ride being evaluated. This value could be determined in direct economic terms such as the passengers' willingness to pay increased fare for a better ride, or in indirect terms such as the passengers' willingness to trade vehicle speed (trip duration time) for an improvement in the vibration characteristics of the ride.

The evaluation of the acceptability of the vibration environment, or ride, of a vehicle must be made in the context of demographic, operational and habitability factors which affect the passenger's overall evaluation of the value of the trip. For this reason, the criterion of ride acceptability must be determined on operational vehicles and by fare-paying passengers. The effect of the bias introduced by using fare-paying passengers in a representative sample of the entire potential customer base must be estimated by a separate investigation.

2. <u>Cost of error in estimating acceptability</u>. Errors in the estimated acceptability of a given ride can be expected. These errors will arise both from sampling errors (use of a finite sample of the population) and methodological inaccuracies in the estimates of trade-off values of ride improvements. If the ride quality specification based on the measured acceptability criteria is too high, the increased cost of vehicle and guideway construction and maintenance will exceed the value to the passengers of the improvements. If the specification is too low, the increased costs will be suffered by the passengers. The cost to the user of basing ride specifications on data of known expected accuracy can be calculated directly from this economic relationship.

3. <u>Cost of accuracy of results</u>. Increased accuracy can be obtained through increased sample size. The value of improvements in the accuracy of the estimates of acceptability can be calculated from the expected costs of errors incurred in using data of different levels of accuracy. The required accuracy is therefore determined through an economic trade-off between experimental costs and the expected costs incurred in accepting the resulting level of uncertainty in the results.

The design of experiments based on the value of the information is common to the field of product marketing, but has apparently not been applied to the investigation of ride quality. This is perhaps understandable given the fragmented approach of previous research, as most of the work has been performed to investigate certain narrow psychophysical questions related to the perception of vibration, and little work has been conducted in support of the development of economically useful ride quality specifications. The methodology for establishing experimental designs for field conditions, such as the setting of fare-paying passengers, is well established, and can be obtained from most introductory textbooks on market research [25].

3.3.4 ADJUSTING FORECASTS OF RESPONSES OF FARE-PAYING PASSENGERS

Results obtained from ride quality evaluations by fare-paying passengers are now compared with forecasts from captive passengers. Differences may be expected both from the effect of operational factors in the fare-paying setting and from differences in the definition of acceptability used in the two settings. Multipliers are "adjusted" to improve forecasts. The operation of factors which are basic to these adjustments is described. Relationships between responses of captive and fare-paying passengers in the first vehicle studied may be used to predict these relationships in the next vehicle.

3.3.5 FURTHER USE OF THE SIMULATOR

Note that the simulator will be available for study of special problems encountered that require intensive examination under controlled conditions. The simulator will be most useful for validating the ride index relationship, and for investigating vibration environments not available on operational vehicles.

3.3.6 DEVELOPMENT OF A DATA BANK

Data acquired as described above are cataloged and entered into a data bank. For instance, the results of the first experiment may consist of two functional relationships for a limited set of conditions relevant to the mode considered:

Ride comfort index = f (vibration factors)

Acceptability = f (comfort)

The ride comfort index relationship can provide the basis for investigating vibration environments peculiar to the second vehicle.

The acceptability relationship provides a basis for evaluating the importance of various non-vibration factors affecting acceptability. Since the form of this relationship for different vehicles probably differs by a constant related to passenger expectations and trade-off criteria, only this constant and the economic costs resulting from the vibration environment must be evaluated.

The advantage of performing the evaluation of ride quality in a series of steps related to transportation modes arises from the similarity of the ride for various vehicles within the mode, and the functional similarities of the different vehicles as perceived by the passenger. Thus, the investigation of the relationships between vibration, comfort, and acceptability for a single mode need only consider a limited range of variables. The extension of the results to a second mode requires only validation of the previously obtained relationships in a similar transportation environment. In this way, only a portion of the complete range of possible combinations of transportation factors need be investigated for each vehicle or for each transportation mode.

3.3.7 AN APPROACH TO THE STUDY OF RIDE QUALITY IN SEVERAL VEHICLES

A programmatic approach to the study of ride quality in several vehicles involves planning the collection of data about ride-ride quality relationships in the first vehicles studied so they can contribute to an understanding of relationships in studies of other vehicles. This is the primary feature of a programmatic approach--all data available at any given time can be compared and used to guide future studies. A general procedure is as follows:

1. For the first vehicle of interest, a captive passenger study is conducted in two steps. The first step is to check out instrumentation for measurement of stimulus variables and passenger response. The procedures and evaluation forms should be developed carefully since they will be used in subsequent studies with some modifications. The second step is to obtain and correlate stimulus and response measures.

2. A simulator with requisite capabilities may be used to examine suspected vibration problems.

3. The ride-ride quality relationships established in the captive passenger study serve as forecasts of relationships to be found in a study which involves measurement of ride-ride quality relationships for revenue passengers. The study of ride evaluations by revenue passengers brings into play the influence of operational factors which cannot, for the most part, be evaluated using captive passengers as experimental subjects.

4. Working backward from evaluations obtained from revenue passengers, we determine which values of V and H and their weights may best predict these evaluations. The variance in revenue passenger responses that is not predicted can be attributed to operational factors, individual differences,

and errors. Predictions may be enhanced by adding demographic factors, trip experience, passenger perceptions of mode of transport, trip time, etc., if these are found to correlate with ride quality measures.

5. The ride-ride quality relationships found for captive and revenue passengers in the first vehicle studied may be thought of as forecasts of these same relationships in a second vehicle. These forecasts may, of course, be substantially in error. An examination of differences between vehicles may lead to hypotheses as to differences between relationships by vehicle. These hypotheses are recorded so their validity can be evaluated when data on ride-ride quality relationships are obtained for the second vehicle. If the relationships between Vehicles 1 and 2 exhibit similarities, we can proceed with added confidence to additional vehicles. If the ride-ride quality relationships between vehicles are dissimilar, data will suggest reasons for the dissimilarities.

6. Proceeding in this manner, as ride quality in additional vehicles is studied, it should be possible to use the growing data bank obtained from prior studies to reduce errors of forecasts. Hopefully, after a few vehicles are studied, ride quality evaluations can be forecast accurately from knowledge of stimulus values with occasional empirical spot checks.

Above in skeletal form is a programmatic approach to the study of ride quality in public transportation vehicles. It involves developing sets of related empirical studies, such that each set addresses an important aspect of the ride-ride quality relationships. The term "set" is used broadly to refer to two or more experiments planned and conducted to explore related areas in such a manner that the results can be compared with some rigor. This requires, among other things, preplotting the related stimulus domains to be explored, measuring responses (of subjects/revenue passengers) in such a way that repairs from the experiments that make up the set are comparable, and, in general, specifying in advance the interfaces among experiments of the set. (As examples, a set might include all experiments that study the impact of vibration characteristic of a mode of transportation; or all empirical evidence to be collected about the ride quality of a particular vehicle type.)

This programmatic approach should be efficient in that: it will utilize a standard set of data collection procedures; it will permit increasing economy in empirical studies by fully exploiting an accumulating bank of data; and it will provide data on ride-ride quality relationships that are comparable for all vehicles.

4. EXPERIMENTAL DESIGNS

Section 3 presented a general strategy for establishing sets of experimental designs for the investigation of ride quality and for relating results within and between sets. Here, the strategy is translated into specific recommended experiments. This chapter outlines requirements for eight designs within the three settings; i.e., simulator, captive passenger, and fare-paying passenger. It then develops in detail three designs, one for each setting. These three designs serve as prototypes for the specific experimental designs which are listed for each of twelve transportation modes.

Initial designs are planned in sequence so we can learn as we go. Learning involves development of instruments to measure ride quality and evaluation of their validity, reliability and practicality; development of means for measuring ride parameters; and development of a program for correlating the measures of ride with measures of ride quality. It involves developing means for sampling among demographic and environmental factors, and development of requirements for efficient administration of designs. Learning involves analyzing data so that those factors, which in repeated instances show little relationship with ride quality evaluations, need not be varied or included in subsequent experimental studies.

As indicated in Section 3, for any concept, transportation mode, or vehicle, a study of captive passengers should be conducted first. This serves several purposes: the experimenter becomes acquainted with the operational vehicle and riders. Instruments to be used in studies of operational passengers are pretested. Special problems that may need more intensive study in simulators or in other contexts are identified and described. The number of subjects used in studies of captive passengers should be small enough that the subjects can be readily handled administratively, but sufficient that summary statistics and tests of association of their responses can be conducted.

4.1 EXPERIMENTAL DESIGN OUTLINES

Shown in Tables 4-1, 4-2, 4-3, and 4-4 are experimental designs ordered so that results of each experiment are self-contained, but so that members of each set contribute to one another, and results from sets can be compared.

Table 4-1 outlines information needed for three experimental designs which apply to captive passengers: one design as a first tryout of a study aboard an interurban train, and a second design which represents an improved version of the first. This second design, being embedded in the first fare-paying passenger study, will allow further refinement of measuring devices and permit correlation of responses from captive and fare-paying passengers. The third design is for rides aboard intra-urban buses.

Table 4-2 presents three design outlines for simulator studies. The first investigates discrimination and preference thresholds. The second and third involve studies of stimulus maskings and summation, and events or spikes superimposed on continuous vibration. The rationale for study of these variables derives from the literature review.

Table 4-3 presents an experimental design for fare-paying passengers aboard trains.

Table 4-4 presents an experimental design outline for evaluation of ride quality aboard an intra-urban bus.

4.2 EXPERIMENTAL DESIGNS FOR THE RIDE SIMULATOR SETTING

This section describes three related experiments which may be conducted using the NASA-Langley Simulator. The experimental designs are presented in the form of a test procedure. Study objectives are to:

Table 4-1. Experimental Design Captive (Paid) Passenger Studies

Experiments and Man-Months Level of Effort	Passenger Characteristics	Independent Variables and Environment Parameters	Measure	Psychometric Approach	Number of Passengers/ Subjects	Data Analysis	Data Interpretation Results
CP-1 (Interurban train) 5-6 hour trip Estimated 18 man-months	Demographic Prior experience Set/expectation	Vibration components Smooth 1-n Rough 1-n Habitability components V + H Coach Seat location	Descriptors of V, H V, H and components For V and H Comfort Acceptability Ride quality Overall ride quality (V + H)	Open-end questions Checklists Rating scales	32 16 per coach Two adjoining coaches	Summary statistics χ^2 Analysis of variance Multiple regression	Descriptor consensus Pretest of scales Suggested modification of scales/ labels for scale pts. Inter/intra individual differences Reliability of scales R.Q. evaluation, comfort, acceptability Effect of independent variables Effect of passenger characteristics Effect of coach/seat location First estimate: predictor algorithm
CP-2 (Embedded in fare-paying train-1) Estimated 6 man-months	Demographic Prior experience Set/expectation	Vibration components Smooth 1-n Rough 1-n Habitability components V + H Coach Seat location	Descriptors of V and H V, H and components For V and H Comfort Acceptability Ride quality Overall ride quality (V + H)	Open-end questions Checklists Modified rating scales based on results of CP-1	32 16 per coach Two adjoining coaches	Summary statistics χ^2 Analysis of variance Multiple regression	Compare with results of CP-1 for stability Test of modified scales Suggested modifications of scales/ labels for scales Compare with fare-paying--1 Inter/intra individual differences Reliability of scales R.Q. evaluation, comfort, acceptability Effect of independent variables Effect of passenger characteristics Effect of coach/seat location Second estimate: predictor algorithm
INTRA-URBAN BUS--CAPTIVE PASSENGERS							
CP-3 (Inter-urban and urban bus Estimated 9 man-months	Demographic Prior experience Set/expectation	Vibration components Smooth 1-n Rough 1-n Habitability components Bus type Interurban Urban or inter-urban run Seat location V + H	Descriptors of V and H V, H and components For V and H Comfort Acceptability Ride quality Overall ride quality (V + H)	Open-end questions Checklists Modified rating scales based on CP-1 and CP-2	32 16 per bus Two different buses	Summary statistics χ^2 Analysis of variance Multiple regression	Compare with results of CP-1 and CP-2 Descriptor consensus Suggested modification of scales Inter/intra individual differences Reliability of scales R.Q. evaluation, comfort, acceptability Effect of independent variables Effect of passenger characteristics Effect of bus type Effect of seat location Predictor algorithm checked against trains CP-1 and CP-2

Table 4-2. Experimental Designs/Schedule -- Simulator Studies

Experiments and Man-Months Level of Effort	Passenger Character-istics	Independent Variables	Measure	Psychometric Approach	Number of Passengers/ Subjects	Data Analysis	Data Interpretation Results
S-1 (included in this project)	Demographic	Vibration: 3 points of origin	Discrimi-nation Preference Comfort accept-ability	Paired comparison Paired comparison 7-pt.scale 9-pt.scale	12 per exper. 3 experi-ments	Summary statistics χ^2 Multiple regression	Ability to discriminate prefer-ences Zones of indifference Inter/intra subject differences Verification of scale values Number of subjective levels of comfort
S-2 S-9 man-months	Demographic	Vibration: concurrent variations of vibra-tion	Discrimi-nation Preference Comfort accept-ability	Paired comparison Paired comparison Scales de-pend on S-1 results	12 per exper. 6 experi-ments	Summary statistics χ^2 Multiple regression	Ability to discriminate prefer-ences Comfort Effect of summation Effect of masking Acceptability Effect of summation Effect of masking Inter/intra subject differences Verification of scale values
S-3 10+ man-months depending on number and intensity of events simulated	Demographic	Vibration: Events in vibration background Jerk Roll Pitch Rapid changes in vi-bration Duration of stimulus presenta-tion	Annoyance level Persistence of annoy-ance in subjects	Scales de-pend on S-1 and S-2	12 per exper. 6 experi-ments	Summary statistics χ^2 Multiple regression	Levels of annoyance by event type/by intensity of event Persistence in subjects of annoyance--decay rate

Table 4-3. Experimental Design--Fare-Paying Passengers Aboard Intra-Urban Trains

Experiment	Trip	Sampling Parameters	Passenger Characteristics	Natural Variations Described, Measured
FPP-1 Regional inter-urban train	(Washington to Philadelphia and return)	Time of day/week Length of trip Differences in: railroads services Geographic areas Load: peak off-peak Propellant: diesel electric turbotrain Special purpose vehicle Aspects of trip: time on train "leg" ridden	Demographic Trip purpose Trip duration Prior experience Set/expectation	V. components H. components O. components Train express local Coach type location Direction of travel

Passenger Evaluations	Psychometric Approach, Instruments	Number of Passengers/ Subjects	Data Analysis	Data Interpretation Results
Responses to natural variations For V, H and components, passenger ratings of: comfort acceptability ride quality Overall ride quality	Open-end questions Rating scales (based on results of CP-I)	N = all passengers aboard	Descriptive statistics Associative statistics X2 Multiple regression Analysis of variance	Evaluation of V. H. O. and components R. Q. Evaluation (overall) Effect on R.Q. evaluation of sampling parameters Passenger characteristics Natural variations Validation of scales Relationship to R.Q. of Comfort ratings Acceptability ratings Further modification of descriptors/scales Relationship of predicted to actual evaluations and estimate - predictor algorithms plus Relationship: CP-2 to CP-1

Table 4-4. Experimental Design--Fare-Paying Passengers Aboard Intra-Urban Buses S

Experiment	Rides	Sampling Parameters	Passenger Characteristics	Natural Variations Described Measured
FPP-Bus-1 Intra-Urban Bus	Conducted in at least two urban areas Sample an adequate percent of riders, trips using shifts of experimenters for two days per city	Time of day/week Length of trip Urban area traveled City bus routes Differences between bus companies (if area served by more than one) Type of bus Load: peak off-peak Express or local Cost of trip Riders using transfers	Demographic Trip purpose Experience riding bus; frequency of rides Set/expectation	V. components H. components O. components All sampling parameters

Passenger Evaluations	Psychometric Approach, Instruments	Number of Passengers/ Subjects	Data Analysis	Data Interpretation Results
Responses to natural variations For V. H. and O. components, passenger ratings of: comfort acceptability ride quality Overall ride quality	Rating scales based on CP-3 (bus) and prior studies	N = all passengers aboard Each bus ridden by an experimenter	Descriptive statistics Associative statistics X2 Multiple regression Analysis of variance	Evaluation of V. H. O. and components R.Q. evaluation (overall) Effect on R.Q. evaluation of sampling parameters Passenger characteristics Natural variations Validation of scales Relationship to R.Q. of Comfort ratings Acceptability ratings Further modification of descripters/ scales Relationship of predicted to actual evaluations and estimate - predicter algorithms plus Relationship: CP-2 to CP-1

1. Determine the ability of subjects to discriminate between specified values of acceleration/frequency of random vibrations for points within the vibration envelope of interurban trains.
2. Determine subject preferences within this domain, and establish preference units.
3. Explore the existence of a so-called Zone of Indifference, using the fraction:

   $$\frac{\text{preference threshold}}{\text{discrimination threshold}}$$

   as a measure of the Zone of Indifference.
4. Examine relationships between preference thresholds and scale values on an absolute scale of comfort.
5. In all the above, examine intra- and inter-subject differences.

4.2.1 DISCUSSION OF NEED FOR SIMULATOR RESEARCH

In spite of many prior studies of vibration, correspondence of findings between simulator studies, between field studies, and between simulator and field studies has been unsatisfactory. This lack of comparability of findings may be due to one or more of the following: semantic problems in evaluative scales; inter- and intra-individual differences among subjects; attempts to crowd measures of discrimination limens, perceptions and ride quality evaluations into the same scale; highly selected sample populations; differences in instructions to subjects; lack of precision in stimulus measurement; imprecision in analysis of data; and different perspectives in its interpretation. Because of these many variations, it is hardly possible to determine which data drawn from the literature are most valid measures of subjective evaluations of ride quality of the American public as passengers. Likewise, it is not possible to identify precisely reasons for differences in findings.

Standards useful in the design of future high-speed transportation systems should apply broadly to all vehicles of interest and should permit prediction of passenger evaluation of vehicles from knowledge of design parameters. Currently, knowledge of relationships between the vibration environment and evaluation of ride quality by fare-paying passengers is not well established. The proposed experiments would help establish the data base for such determinations. Each of the five objectives of the study summarized on the prior page can contribute.

Objective 1

Discrimination units for changes of amplitude and frequency of vibration. Establishment of discrimination units within the amplitude/frequency envelope of public transportation systems can be of substantial value. The ability of passengers to sense changes in vibration expressed in discrimination units and referenced to amplitude and frequency can indicate the (minimum) amounts of change needed to produce a detectable improvement in ride and ride quality evaluations.

Objective 2

Preference thresholds, units. Even though passengers can discriminate between two vibration conditions, they may not prefer one to another. Establishment of preference units can serve two purposes: preference units can be compared with discrimination units to establish Zones of Indifference; they can be used to validate scale intervals for scales designed to measure ride quality.

Objective 3

The practical significance of the Zone of Indifference concept is that for small changes in the vibration environment there may be no correlation between changes of the stimulus and the perceived comfort of the ride. Even though passengers can discriminate between different stimuli, it does not follow that they prefer one to the other. People are adaptable. There may be substantial excursions of parameters of the stimulus to which people readily adapt, and for which a representative subject sample would exhibit no marked preferences. The concept is obviously important for vehicle/guideway design, as well as vehicle interior design for habitability. If such Zones of Indifference do exist, the larger the zone, the greater engineering design tolerances permitted, and in many instances, the less stringent the requirements for operations and maintenance. (Conceivably, the Zone of Indifference concept, if valid, could identify areas of overdesign.)

The probable existence of Zones of Indifference and their size can be explored quantitatively using discrimination and preference data. The basic comparison is between discrimination unit size as the denominator, and the size of the preference unit as the numerator. Thus:

$$\text{ZI (amplitude, frequency values specified)} = \frac{\Delta \text{ preference}}{\Delta \text{ discrimination}}$$

The lower limit of the fraction is 1; the upper limit remains to be determined. The larger the fraction, the greater is the Zone of Indifference, and the greater are the allowable system design tolerances.

<u>Objective 4</u>

Verification of scales. Disagreements among results of different studies of ride quality have been noted. Evaluation of ride is readily a two-staged process: the subject feels the vibration; then he reports the vibration in words. Different subjects may not "feel" the same vibration in the same way due to somatotype. Even feeling the same vibration, they may not choose the same term to describe their feelings. An external criterion for evaluating various absolute scales is needed. Preference units can be established and used to evaluate scale intervals of absolute scales that employ adjectives or adverbs.

Objective 5

Need for measures of inter- and intra-subject* variances. Typically, studies in simulators and studies of passengers in operational vehicles have not replicated stimulus conditions using the same subjects. Conceptually and practically, it is quite important in developing means by which passengers may evaluate ride quality, to know to what extent the observed variance of the responses is attributable to inter- and intra-subject differences. As one example, if differences obtained are primarily intra-subject, future studies do not need to be overly careful in selection of subjects; if, however, differences are primarily inter-subject, results obtained from particular subject groups--for example, pilots--might not at all be representative of the users of public transportation systems.

4.2.2 EXPERIMENTAL DESIGNS FOR RIDE QUALITY SIMULATOR SETTING

It is recommended that selected areas within a vibration envelope similar to that characteristic of inter-urban trains be examined.

Experimentation would consist of three experiments during which all stimulus input instructions to subjects would be controlled by preprogrammed tape. The three experiments would each investigate one of the conceptual areas previously discussed.

Experiment I: Establish discrimination thresholds for use in analyzing the results of previous simulator research and for establishing Zones of Indifference.

Experiment II: Establish Zones of Indifference for changes in the characteristics of the rides of operational vehicles.

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*By inter-subject differences, we mean consistent differences between different subjects to their evaluations of ride quality. By intra-subject differences, we mean variations or shifts in evaluations of ride quality by the same subjects, when exposed repeatedly to the same stimuli.

Experiment III: Determine the usefulness and accuracy of various rating scales in obtaining passenger ratings of ride comfort and acceptability.

The results of each experiment can be used to establish the detailed test plan for the next experiment. Discrimination thresholds will be combined with data on preferences to establish Zones of Indifference. The Zone of Indifference can provide a basis for evaluating the relative sensitivity of various rating scales.

Each phase of each experiment would require one session (a period of three hours) at NASA-Langley Research Center using its Passenger Ride Quality Apparatus. Each session would consist of six runs using the simulator. A run would be a twenty-minute time period aboard the simulator during which subjects would be exposed to 20 to 24 pairs of ride segments, or to 20 to 30 single ride segments. Two groups of six subjects each would be rotated such that each group would experience three runs per session.

4.2.2.1 The NASA-Langley Simulator

The recommended simulator experiments are based on the use of the NASA-Langley Ride Quality Apparatus. This simulator operates in three degrees of freedom, with acceleration limited to .5g. The simulator can be completely preprogrammed by analog tape input. Stimulus values, stimulus duration, presentation schedule, etc., may be taped along with voice instructions to subjects. (See Clevenson and Leatherwood, [15]; Stevens and Clevenson [72].) The vibration of the simulator may be measured by accelerometers mounted on the floor of the apparatus and at the point of impact to subjects through accelerometers in the cushion of simulator seats. The output of these accelerometers are recorded during the performance of each test. Seats from the available NASA-Langley seat pool, which most closely resemble Metroliner seats, may be used. (See Dempsey and Leatherwood [19].)

4.2.2.2 Subject Population

A locally obtained sample population of 36 subjects should be used to represent the general mass transportation population. These subjects may be obtained from the existing NASA-Langley subject pool. Safety requirements of the NASA-Langley simulator will, however, limit the sample to physically fit subjects eighteen years of age and over. All subjects must complete the NASA-Langley medical form and be certified as acceptable by NASA personnel.

The following demographic information should be obtained from all subjects: age, sex, income level, occupation, housing pattern, and transportation experience.

4.2.3 EXPERIMENT I

Experiment I is designed to establish discrimination thresholds both for simple (single-frequency, single-axis) vibration environments, and for the complex (multi-frequency, multi-axis) environments.

Most previous research in simulators has concentrated on simple vibration environments, and has generally investigated the relationships between frequency and/or amplitude of vibration and the averaged responses of experimental subjects. Stimulus conditions have been varied over a sufficient range so that there have been clear-cut changes in the responses from subjects. In varying stimulus excursions in sufficient amounts to obtain sizable differences in averaged responses of subjects, these experiments have frequently exceeded the limits of vibration experienced on operational vehicles. Further, published reports extrapolate the relationships from the means of these responses often without reporting intersubject or intrasubject differences. Much of the emphasis of the research outlined in this proposal is applied to the determination of the extent of changes in the ride that will not result in changes in passenger evaluations of ride quality.

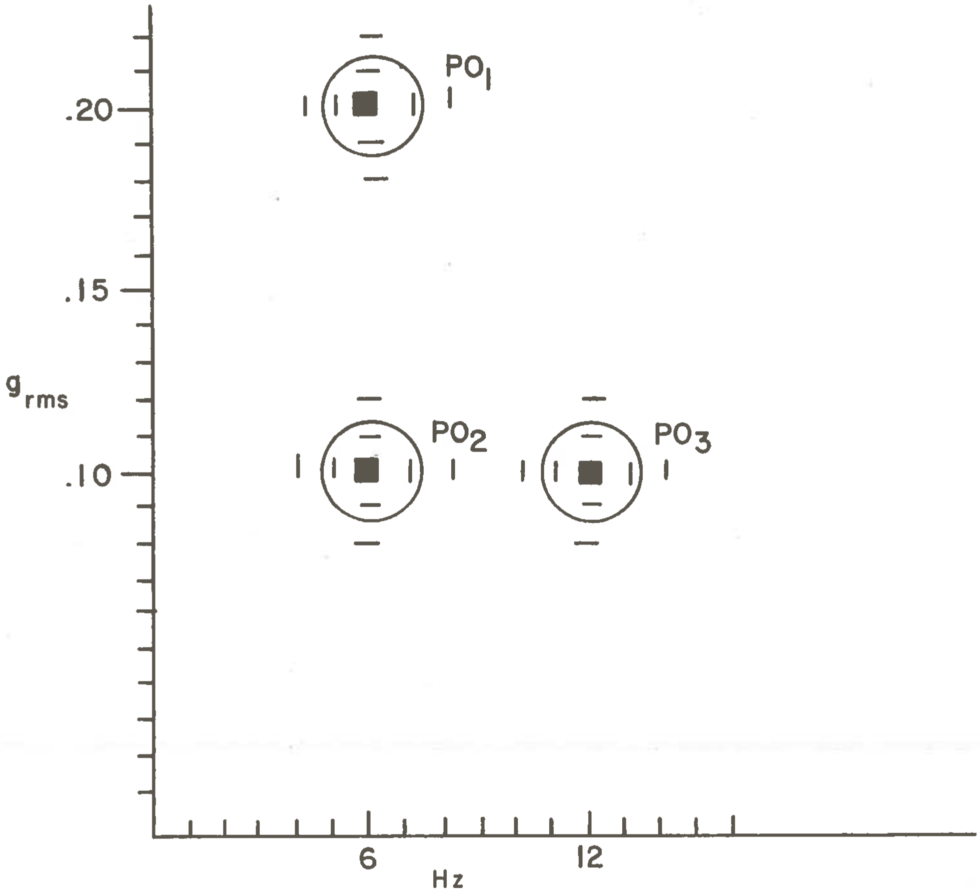
Little simulator research has been performed using the complex vibration environments characteristic of operational vehicles. Such studies are required to bridge the gap between basic psychophysical studies of response to vibration and the need for ride quality evaluations of real vehicles.

The three test sessions recommended for Experiment I are each designed to investigate certain aspects of the concept of discrimination thresholds as they relate to previous research and to the investigation of ride quality of operational vehicles.

4.2.3.1 Experiment I, Session 1

Purpose--The purpose of this portion of Experiment I is to determine the discrimination thresholds for changes of frequency and amplitude of single-frequency sine wave vertical vibration. This simple vibration environment has been extensively investigated in previous studies. The need to use the results of these previous studies in the further evaluation of ride quality requires that the discrimination thresholds be explicitly investigated.

Selection of Points of Origin--Within the frequency/amplitude envelope, three points of origin are to be designated. These points should be designated so as to explore, systematically, discrimination capability at important points of the envelope, so that discrimination and threshold limens can be compared between two well-separated points when frequency is held constant and amplitude is varied; and so that these limens can be investigated at two well-separated points as amplitude is held constant and frequency is varied. Exact points are to be designated based on a review of the vibration envelope of passenger trains and after preliminary tryouts in the simulator. For illustrative purposes, points of origin are shown in Figure 4-1. The frequency and amplitude of the ride segments can be controlled during the experiment using the ride generator controls on the operator's console of the NASA-Langley ride simulator.



☐ Points of origin. Best guessed discrimination thresholds are represented by circles.

— Stimulus units

Figure 4-1. Stimulus Points for Experimentation

Experimental Procedure

Run 1: Estimation of discrimination threshold for frequency changes. Pairs of rides are to be presented, each ride being 5 to 8 seconds in duration with a few seconds between the rides. One of the rides of each pair is to be at the standard frequency; the position of this reference ride in the pair is to be randomized. The difference between the standard ride and the altered ride is to be a change in the frequency of the altered ride. The experimental order of the changes in the difference is recommended to be in accordance with the "up and down" experimental design, which is sometimes called the "Bruceton" method. The details of this method, and its use in estimating thresholds, is described in more detail in the literature [53, Ch. 10, p. 22].

Run 2: Estimation of discrimination thresholds for amplitude changes. Procedure is to be the same as for Run 1, except the alteration in the ride is to be a change in the amplitude of the vertical vibration.

Runs 3-6: Detailed and accurate determination of discrimination thresholds.

A number of stimulus differentials are to be chosen so that the range is from no difference reported by the subjects to 100% correct responses. Stimulus pairs are to be presented as in Runs 1 and 2, the choice of difference magnitudes and the altered parameter (frequency or amplitude) being randomized. The thresholds around each point of origin are to be investigated in both the frequency and amplitude directions as shown in Figure 4-2. It is recommended that the data be analyzed according to the Karber method to determine estimates of the mean and standard deviations of the discrimination thresholds. This method would be sufficiently accurate for the analysis of the data collected in a single session. Extensive experimental investigation of thresholds might better rely on the Probit Method of Analysis, assuming that the required criteria of normality of the errors

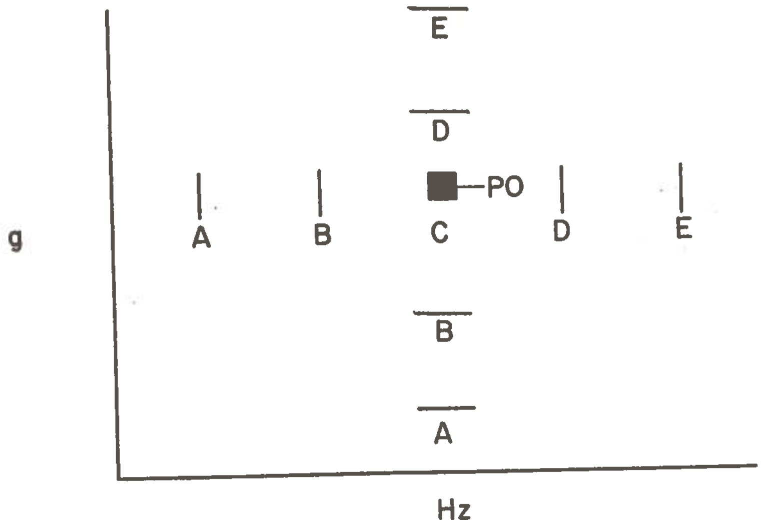


Figure 4-2. Stimulus Points Around Each Point of Origin

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are met. Both of these methods are described in detail in the literature [53, Ch. 10, p. 3].

Subject Responses--The same response formats will be used for discriminations and preferences. Each subject must record his responses to each pair of rides. Ordinarily, we would prefer a forced choice method of recording, with members of stimulus pairs being labeled the same or different. However, since we do not wish to force preference judgments in Experiment II, and because we wish to compare discriminations and preferences using the same formats, subjects will be given three options:

In amplitude:

First ride was smoother__ rougher__ equal__ to second ride.

In frequency:

First ride was higher__ lower__ equal__ in frequency to second ride.

Possible extensions of the investigation of discrimination thresholds--The results of the Session 1 experiment will show the basic relationships between vibration frequency, amplitude, and discrimination thresholds. This data is required in the preparation of the simulator experiments to follow, but much more work would be required to completely plot out the relationships among these factors.

An attractive approach to additional investigations along this line would be to determine the effects of simultaneous changes in frequency and amplitude on the size of the discrimination threshold. This could easily be accomplished through the use of a fractional factorial experimental design. This approach would be successful only if the threshold is an additive function of the changes in frequency and amplitude, and if these parameters do not interact. If additional investigation along this line is planned, the Session 1 experiment should include a test of validity of the assumption of the independence of these factors.

4.2.3.2 Experiment I, Session 2

Purpose--The purpose of this portion of Experiment I is to determine the discrimination threshold for changes in amplitude of a complex vibration environment in the vertical direction in the presence of vibration in the lateral and roll directions. This data is necessary to extend the results of Session 1 to the world of real operational rides where vibration is complex in spectral content and multi-axial in direction. The basic question to be answered is simple: how much change in the vertical vibration amplitude of a real ride will result in a barely detectable difference in the roughness of the ride?

Selection of points of origin--Recordings of the ride of two dissimilar vehicles should be chosen. It is recommended that these be two dissimilar railroad passenger cars operating over the same track, such as the turbo-train and a conventional coach, or self-powered Metroliner car and a conventional coach. Alternatively, the ride of a single car over dissimilar guideway (bolted versus welded rail) could be used. It is important only that the two rides be distinctly different.

Experimental Procedure

Run 1: Estimate the discrimination thresholds for changes in amplitude of the vertical vibration for the two rides in the absence of vibration on the other axes following a procedure similar to that used for Session 1, Run 2.

Runs 2 and 3: Investigate discrimination thresholds for amplitude changes of the vertical vibration occurring alone for the two rides. Use the procedure used in Session 1, Runs 3-6.

Run 4: Estimate the discrimination thresholds for changes in the amplitude of vertical vibration in the presence of lateral and roll motion.

Runs 5 and 6: Investigate in detail the discrimination thresholds estimated in Run 4, this session.

A comparison of the estimates of discrimination thresholds determined in the absence of other motion and then in the presence of lateral and roll motion will provide basic data on the possible effects of masking and interaction affects among vibrations in different directions aboard operational vehicles.

4.2.3.3 Experiment I, Session 3

Purpose--The purpose of Session 3 is to further extend the investigation of discrimination thresholds of two operational rides to the case where the amplitude of the vibration on all three axes (vertical, lateral, and roll) is changed simultaneously by an equal amount. This session will provide an indication as to whether the amplitude of vibration on one axis is an important reference point in the estimation of the change of amplitude vibration on a different axis.

Experimental Procedure--Same as used in Session 2, Runs 4, 5, and 6; change amplitude of vibration in all axes by same amount.

4.2.4 EXPERIMENT II

Experiment II is designed to establish preference thresholds for changes in the amplitude of the vibration environment. This preference threshold is directly related to the Zone of Indifference, and therefore has important implications for the establishment of ride quality specifications.

The ride segments to be used in Session 1 of Experiment II should be the same as those used in Experiment I. Preference thresholds are to be estimated for each ride as a function of change in amplitude of the vibration. Then preference thresholds are to be estimated where Ride 1 is compared to Ride 2. The hypothesis may be advanced that the preference threshold is larger where the rides are dissimilar due to differences in the evaluative criteria used by different passengers. If this is shown to be the case, it will have important obvious implications for the estimation of the relative comfort and acceptability of different vehicles.

Elapsed time likely enters into the acceptability of types and levels of vibration in several ways. A broad relationship between tolerance for vibration and elapsed time is reflected in the ISO standards. A more specific area of interest is the predictability of periodic events by passengers. A reasonable hypothesis would be that the better the passengers are able to predict the onset of vibration events, the more readily they will become acclimated to their presence.

4.2.4.1 Experiment II, Session 1

Purpose--The purpose of this portion of Experiment II is to determine preference thresholds for the two rides used in Experiment I, to establish amplification factors which, when applied to Ride 2 make it equal in comfort (or preference) to Ride 1; and to determine preference thresholds based on comparison of the comfort of dissimilar rides.

Experimental Procedure--The same points of origin and procedures as described in Experiment I, Session 3 will be used to plot preference limens. We would expect preference limens to be larger than discrimination limens. A first estimate of preference limens should be made by experimenters after discrimination tests have been administered. Guessed preference units may then be used to establish pairs for presentation as described above for discriminations. Ten stimulus pairs should be presented around the point of origin for each ride. The procedure should be repeated to provide a reliability check. The order of the rides in each pair and the order of the different magnitudes of differences should be randomized.

Two groups of six subjects each should be used during the session. The groups should be alternated to avoid subject fatigue. Each subject would participate in three test runs.

Run 1: Establish amplitude factors so that Ride 2 is equal in comfort to Ride 1. The amplitude of the vibration on each axis can be controlled from the operator console. If a method is used so that the subject responses are known immediately to the experimenter, the point of equal comfort can be located by an "up and down" experimental design. Otherwise, the amplitude differences must bracket the expected preference threshold.

Runs 2 and 3: Investigate in detail the preference thresholds for each of the two rides. Use the discrimination thresholds as the first estimate of the preference thresholds and follow the procedure used in Experiment I, Session 3.

Run 4: Establish the approximate preference threshold for changes of amplitude of Ride 2 with reference to Ride 1. This will require that the following vibration amplification factors be measured:

> The decrease in amplitude of Ride 2 so that it is preferred to Ride 1 by 75% of the subjects.
>
> The increase in amplitude of Ride 2 so that Ride 1 is preferred by 75% of the subjects.

Runs 5 and 6: Investigate in detail the preference threshold for Ride 1 versus Ride 2.

Subject Responses--It is recommended that the same type of scale be used in the investigation of preferences that was used in the investigation of discrimination thresholds. Subjects should be given three options in responding to each pair of rides: prefer first ride; no preference; prefer second ride.

Analysis of Data--Data analysis should take the same form for both discrimination and preference sessions. A discrimination threshold is defined as the ability to discriminate correctly 75% of the time. A preference threshold is defined as the expression of preference 75% of the time. Responses for all subjects for each point of origin should be tabulated as follows:

	Amplitude Excursion			Frequency Excursion		
Step Interval	Smoother than A	Rougher than A	Same as A	Smoother than A	Rougher than A	Same as A
0	a	b	--	a	b	--
1						
2						
3						
4			i			i

Plotting response percentages as a function of amplitude using the Karber method allows determination of discrimination limens.

The same procedure can indicate preference limens for each point of origin. For each point of origin in Experiment II, the Zone of Indifference with respect to amplitude is defined as

$$ZI = \frac{\Delta \text{ preference limen}}{\Delta \text{ discrimination limen}}$$

The Zone of Indifference should be calculated for amplitude changes of each ride and for Ride 1 versus Ride 2. In all cases, demographic data should be correlated with the individual threshold estimates to determine significant relationships. The results of this analysis would provide insight into changes in the Zone of Indifference that may occur as a function of vibration conditions and inter-subject differences.

4.2.4.2 Experiment II, Session 2

Purpose--The purpose of this portion of Experiment II is to determine the effect of the predictability of repetitive ride events on the comfort of the ride. The general hypothesis is that passengers can adjust to periodic vibrations, or at least to some types of such vibrations; and that having adjusted, they will evaluate periodic vibrations as more comfortable than randomly occurring vibrations of the same magnitude that the subject's musculature and/or conscious awareness cannot "predict."

The objectives of the experiment are to evaluate ride comfort evaluations as a function of:

> Degree of autocorrelation of ride motion for a selected time interval (five seconds).

Types and amplitudes of ride motion.

Independent variables--Independent variables are to consist of:

Degree of autocorrelation

- Approaching 1.00
- Approximately 0.5
- Random, i.e., essentially 0.00

Simultaneous linear, horizontal and vertical ride motions with different amplitude levels

Experimental designs--Although this experiment could be run using the matched-pair stimulus procedures recommended for other sessions in Experiments I and II, a more economical approach would be to use the rating scales developed in Experiment III to measure subject evaluations of the comfort of the ride.

A first approximation of the experimental design using this rating technique is shown in Figure 4-3.

Type of Ride Motions	Amplitude of V	Value of $R_x(T)$		
		1.0	0.5	0.00
A	low			
B	low			
C	low			
A	high			
B	high			
C	high			

Figure 4-3. Experimental Design for Evaluation of Associations between Autocorrelated Vibrations and Comfort Ratings

The above design provides 18 cells. Order of presentation should be randomized.

When data are collected, each cell will contain evaluations by six subjects on a general comfort and discomfort scale, and on bi-polar scales describing more specific type motions and/or on scales defined by descriptive terms found to correlate with variations in vibration stimuli in prior testing.

<u>Types of ride motion</u>--The autocorrelated ride motions of interest are repetitive discrete events resulting from step inputs into the vehicle suspension from the guideway. These events are superimposed on a ride which is a continuous background vibration arising from vibrational resonances of the vehicle structure, onboard propulsion equipment and other machinery, and short-wave length, uncorrelated deviations in the guideway. Examples of event-type ride motions are switches, turnouts, and rail joints on railroads, pavement joints and rapid braking applications on buses, and buffeting of aircraft.

The ride events can be objectionable to the passengers psychologically if they distract attention from a preferred activity, and physically if they demand muscular effort to resist. It has been hypothesized that the acceptability of the events is correlated with their predictability; i.e., highly autocorrelated events will be less objectionable than those whose occurrence can be predicted and anticipated.

The FRA has in its data library examples of smooth rides and of various types of events experienced in train rides. The events are generally characterized as underdamped oscillations of the main suspension components of the vehicle, i.e., vertical bouncing correlated with some motion in the other axes, all of which damps out in a second or two depending on the characteristics of the suspension.

Generation of program tape for NASA/LRC passenger ride quality Apparatus--The motion of the NASA simulator is controlled by means of a pre-programmed analog tape which defines the accelerations of the floor of the passenger compartment. Presently, these tapes are prepared by tape-to-tape or oscillator-to-tape dubbing, and the control over the accuracy of the tape is entirely a function of operator skill. Because it is not currently possible to splice short segments of ride together without a step, or simulator jerk between the segments, it is not practical to attempt to construct the program tape for the ride event autocorrelation by this method. NASA/LRC is currently considering an unsolicited proposal to develop a method of putting the program tape generator procedure under computer control, thereby achieving greater accuracy and flexibility in the generation of program tapes.

Two alternate, all-analog methods of generating the program tape could be used. The first would be to record a smooth ride onto the program tape, periodically increasing the amplitude for a one-second period in order to create an event. The periodicity of the events, in the terms of their autocorrelation, would meet the requirements of the experimental design. This technique is objectionable in terms of realism--events are not simply an increase in amplitude of the background vibration, but are a superimposed component having specific frequency and damping characteristics. In addition, this manual control procedure would be inherently inaccurate in terms of amplitude and duration.

The analog procedure which is recommended would be to construct electronic circuits which put out under-damped transient signals in response to a step function input. The frequency and damping characteristics of the output of this circuit would be designed to match the fundamental characteristics of an event on a passenger rail car. The output of this circuit would be added to a smooth ride being recorded onto the program tape. The events would be triggered at a mean interval of five seconds; the intervals between triggering this circuit would be controlled to give the required autocorrelation of the events; the ratio of amplitudes of the event on the vertical, lateral, and roll channels would define different types of events such as bounce, lateral jerk, and roll. This technique would achieve the most realism and best control that are possible using currently available techniques to build the simulator program tape.

Reliability/number of cases--The basic design will be replicated once using the same (six) subjects to obtain intra-subject reliability data. Inter-subject reliability will be determined by application of Hoyt formulas* to analysis of variance results.

The experiment will be repeated on a second group of six subjects to provide an N of 12. Current indications are than an N of 12 will provide stable and reliable evauations.

Subjects--Subjects will be selected from the subject pool available at NASA-Langley. The simulator accommodates six subjects per run. Recent findings as to possible differences between sexes in ride quality evaluations suggest that three males and three females be included per run.

Data Analysis--Multivariate statistical methods are appropriate, along with the Duncan multiple range test. Data should be analyzed to indicate:

1. The consistency with which subjects discriminate between the stimuli--Runs 1 and 2 for subjects and ride stimuli.
2. The effect of autocorrelations for the three autocorrelation values for each stimulus amplification. This may be done separately for the first and second rides. (Present studies in the NASA-Langley simulator show that while inexperienced subjects discriminate vibration well in the first run, ability to discriminate is further improved on the retest.)
3. Analysis of variance to the degree determined appropriate will indicate interactions existing

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*Johnson, Palmer, Statistical Methods in Research, Prentice Hall Inc., Englewood Cliffs, New Jersey, 1950, pp. 134-136 between stimuli responses, measuring instruments, etc.

4. Application to Duncan Multiple Range tests will provide a preliminary indication of stimuli falling within subject Zones of Indifference.

5. Step-wise multiple regression analysis may be used to indicate the contribution of each variable/combination of variables to the multiple correlation coefficient.

6. Auxiliary findings. Some findings such as sex differences should be checked both as a matter of interest and to reduce the size of the error term per degree of freedom.

Interpretation of Data--The issues of central interest are:

> Whether comfort ratings by subjects show that subjects "adjust" to autocorrelated vibrations. If so, extent of adjustment.
>
> If the physiology/musculature does adjust, whether this adjustment is "across the board" or whether it holds for certain types/amplitudes of vibrations or events but not for others.

Positive findings from recent experiments at NASA-Langley suggest that if subjects can make such adjustments, the rating scales being used are sufficiently reliable to provide valid quantitative indications.

To go a step further, assuming positive findings, the three points on a hypothetical autocorrelation scale with a range of 1.00 to .00 can be related to ride comfort ratings to plot "trade-offs." The function--assuming positive findings--might look something like Figure 4-4.

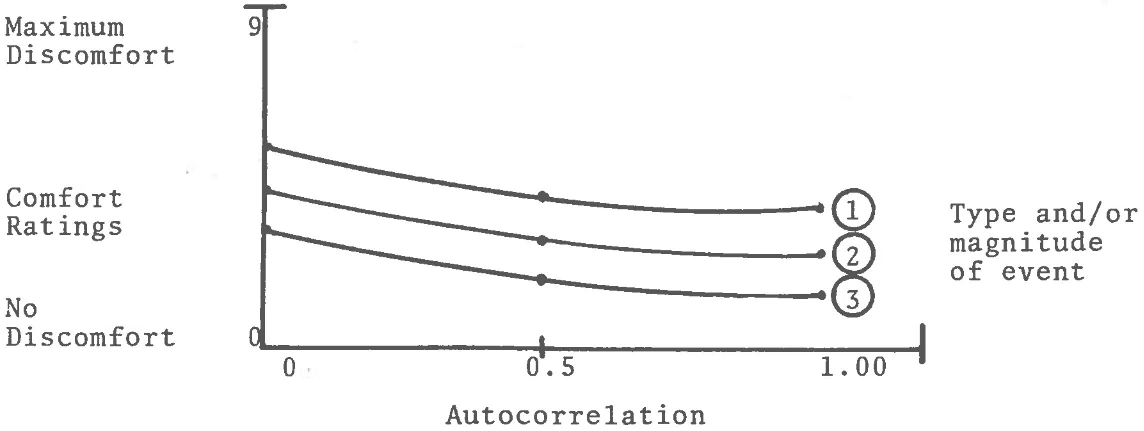

Figure 4-4. Hypothetical Relationships Between Ride Comfort Ratings and Autocorrelations of Vibration

Results could be further extended by establishing values at other points along the autocorrelation continuum, and by varying the degree of autocorrelation and mean time between events. Such results would be of substantial interest from a human factors view; they should also be of interest and assistance to engineers who design and maintain vehicles and guideways.

4.2.5 EXPERIMENT III

The investigation of the ride of operational vehicles requires that ratings of ride quality be obtained from the passengers for individual segments of ride. Since the matched pair stimulus techniques used in the simulator are not applicable to the operational setting, a psychometric scale must be used to obtain ratings of the comfort of each ride segment. A number of such scales have been investigated during this study, and the results are reported in Chapter 5 of this report.

It is the purpose of Experiment III to determine the precision of the results obtained by using psychometric scales in an operational setting. Preference units established in Experiment II should be compared with absolute judgments as recorded by rating scales.

Working from preference units established in Experiment II, for each of the points of origin, ride segments should be presented that represent differences of none, one, and two preference units respectively. A preference unit is, of course, defined by two points; i.e., two physical stimuli that vary by a known amount im amplitude.

Experimental Procedure--Two groups of six subjects are to be used. Each group will participate in three 20-minute test runs.

Runs 1 and 2: Confirmation of preference thresholds for two rides. Each ride will be presented at five levels of amplitude, adjacent levels differing from one another by one preference threshold. The levels will be adjusted using the results obtained in Experiment II so that Level 3 of Ride 1 is equal in preference to Level 3 of Ride 2. Matched pairs of ride segments are to be presented, each consisting of one segment of the first ride and one segment from the second. These pairs are to be constructed as shown in the following matrix.

			B		
A	1	2	3	4	5
1	x	x	x	x	x
2	x	x	x	x	x
3	x	x	x	x	x
4	x	x	x	x	x
5	x	x	x	x	x

The order of the pairs should be randomized. The scales and analysis procedures should be the same as used in Experiment II, Session 1.

Runs 3 through 6: Relationships of scale units to preference thresholds. The 25 ride segments, defined by amplitude, which were used in Run 1 to define preference units, should be presented to subjects one stimulus at a time. Subjects should be instructed on each presentation to evaluate comfort using the scales which are being evaluated.

Analysis Procedures--It is assumed that the best scale will be that wherein scale units are most highly correlated with preference units. Comfort ratings should be compared to ride acceptability ratings as a check on their correlation using linear regression and cross-correlation analysis methods.

Demographic descriptors should be correlated with ratings to identify consistent relationships if they occur. A chi square statistic can be used for this purpose.

4.3 EXPERIMENTAL DESIGN FOR THE CAPTIVE PASSENGER SETTING ON AN INTERURBAN TRAIN

This study would examine the relationships between ride and ride quality on a train using the FRA Portable Ride Quality Package to measure vibration, and first versions of rating scales to be completed by captive or paid passengers to measure ride quality. Concurrently, information would be gathered to help develop more refined rating scales for use by fare-paying train passengers to evaluate ride quality.

Specific objectives are:

1. To determine what terms subjects employ to evaluate components of vibration and habitability.
2. To measure the impact of suspension systems, smooth track and various types of rough track on passenger evaluations of ride.
3. To discover whether demographic and psychological factors consistently influence evaluations of ride.
4. To develop procedures and to pretest forms to be used to collect ride quality evaluations from fare-paying passengers.

4.3.1 BACKGROUND

Few experiments have adequately studied the relationship between passenger response to vibration and precise measures of the vibration produced in operational vehicles. Those which have carefully measured vibration (i.e., Ferguson and Britton [20], Urabe [75], Matsudairi [48], Loach and Wilson [84,42], etc., in field studies; Miyoshi and Sakamoto [52], simulator; and Hirshfield [31] in a lab study) found different passenger responses. Other investigators (Wahmann and Fleishman [81], Saks, Yates and Goodman [61], etc.) have developed response scales but have not related these to quantitative measures of vibration or variations in vibration. It is therefore necessary to solicit passenger response, through carefully structured questionnaires, at specified intervals of a vehicle ride, as vibration components are being accurately measured.

Several issues need to be examined.

1. a. Descriptors for ride quality scales. In view of the need to prepare for future studies of ride quality, attention needs to be given to the terms passengers employ to describe the vibration environment and its components.

   b. First versions of rating scales can be evaluated concurrently with this effort to identify terms passengers use to describe various aspects of ride.

2. The dynamic movements that constitute vibration are complex and difficult to express mathematically. Many possibilities are being studied. Use of the subjective ride quality criterion and concurrent measurement of vibration provide a means of determining which vibrations make a difference to passengers and which mathematical descriptions of vibrations provide the best forecasts of passenger comfort.

3. Demographic and psychological factors may or may not influence evaluations of ride quality. While collecting information, it will be possible to determine the extent to which such factors are correlated with passenger evaluations of ride quality.

4. This study is conceived of as a first model of a prototype study of paid passengers to be used to study ride quality in any new vehicle. After it has been completed, methods should be refined as required for application to new vehicles.

5. As in the simulator study, measures of intra- and inter-subject variability in ride evaluations are needed.

4.3.2 GENERAL EXPERIMENTAL PLAN

This study would provide a precise means of comparing measures of ride as generated by all dynamic movements of the vehicle and vehicle interior design (i.e., habitability) with passenger ride quality evaluations. A five- or six-hour train trip for paid and pre-instructed passengers would allow repeated observations at pre-selected track locations. Measures of passenger response would be obtained by having passengers rate characteristics/components of the stimulus environment, and habitability features defined as important from the literature review. The FRA Portable Ride Quality Package would be used to obtain quantitative measurements of the vibration. Prior measurement of track segment characteristics will allow prespecification of smooth and rough segments of the ride along the selected track or guideway. Thus, by taking advantage of existing differences in track, the impact of vibrations on ride comfort evaluations could be measured repeatedly.

4.3.2.1 Selection of Subjects

Subjects should be selected for demographic factors such that the subject pool is similar to AMTRAK ridership in terms of age, sex, and income level. The subject pool should be partitioned on the basis of the mean of these factors such that a full factorial design is obtained with three factors and two levels. A subject pool of 32, which is about the number which can be easily handled in a single test run will result in four subjects in each cell of the experiment. The 32 volunteer paid subjects could be obtained with the cooperation of the state employment commission and should be selected such that there will be four subjects in each of the eight cells.

4.3.2.2 Designation of Experimental Vehicle and Track Conditions

The vehicle environment/track study would involve a six-hour round trip between Washington, D.C. and Philadelphia aboard METRO. Additional time is allotted for briefing subjects and for lunch. AMTRAK would be asked to provide two adjoining coaches. Vinje [80] has indicated a difference in ride for middle and end seat locations. Therefore, AMTRAK would be asked to reserve seats at the middle and at one end of each coach. AMTRAK would be asked to provide complimentary tickets and would be provided with a report.

Selected segments of the track, producing smooth or rough ride, would be pre-designated and pre-identified by analysis of existing FRA data on the track to be used. Track segments and vehicle accelerations would be categorized by their vibration characteristics and by an appropriate descriptor: stop/start, turn, crossover, diamond crossing, curve entrance, transit, or exit. At least two segments of each type would be sampled.

4.3.2.3 Measurement of Vibrations

Smooth track segments and the various types of rough track are to be identified from FRA track geometry measurement reports and from data previously obtained using the FRA Portable Ride Quality Package. Visual inspection of graphic presentations of track vibration characteristics and track geometry records will identify smooth and rough track segments on both tangent and curved track. The test segments will be selected such that, to the extent feasible, equal numbers of smooth and rough test segments are presented so as to control for subject "set" or "expectations." The vibration environment should be recorded during the test and the records should then be analyzed to describe each segment of ride. The roughness of selected segments can then be summarized in numerical terms, such as PSD, rms levels, etc.

Subjective ratings of ride quality presume concomitant measurement of physical vibrations experienced by the raters. Assuming coach and seat location as independent variables, four Portable Ride Quality Packages would be required, one for each subgroup of eight subjects.

4.3.2.4 Measurement of Habitability

Habitability components listed below are to be either measured or described as appropriate for each coach:

Noise
Temperature
Air quality
Seating
Interior lighting
Windows
Entrance/exit
Decor
Handholds
Baggage accommodations
Toilet facilities

4.3.2.5 Measurement of Subjective Response to V and H

With respect to measuring ride quality, a lack of agreement exists between investigators about appropriate words with which to translate engineering vibration terminology into the terms passengers use. The first portions of the experiment involve an attempt to determine adjectives, or descriptors, most frequently used to describe various types of vibrations. Both unstructured formats and checklists can be used to solicit descriptors from passengers. This portion of the experiment may be conducted during a train trip from Washington, D.C. to Philadelphia.

During the trip to Philadelphia, passenger response should be obtained through open-ended questions, asking each passenger to describe the smooth or rough vibration event just experienced. Following the collection of these response sheets, passenger response should be solicited to a series of vibration descriptors culled from the literature. The passengers should be asked which descriptors best describe the just-experienced vibration event.

4.3.2.6 Return Trip

This portion of the experiment would obtain passenger ratings for comfort and acceptability of vibration, habitability, and their components. A nine-point scale used to elicit comfort and acceptability responses in the NASA-Langley simulator should also be used to provide a means of relating responses in the simulator to those obtained in an operational environment. Comfort and acceptability ratings are to be obtained for smooth and various rough vibration events during the return trip. Habitability component ratings are to be obtained for both portions of the round trip.

Note that descriptors obtained during the Washington-Philadelphia leg of the trip are to be used along with the scales to build/refine scales to be developed later.

4.3.3 EXPERIMENTAL PROCEDURES

4.3.3.1 Trial Run

Prior to actual experimentation, the experimenters should make at least one trial/rehearsal run aboard a METRO car.

Three experimenters should be used. One would keep track of train location. He would be responsible for notifying an experimenter in each of the two coaches when to alert passengers, and when to give passengers the signal to evaluate vibrations and make ride quality ratings. During the trial trip, this experimenter would use the FRA Portable Ride Quality Package and track records to become completely familiar with the track map, mileposts and other indicators of the track segments designated for passenger evaluation. He would also record the time at which mileposts are passed, ride segments attended to and evaluated, etc.--in short, he must at all times know precisely where the train is and assure that data are being obtained as planned.

The other two experimenters would have responsibility for instructing subjects and for passing out and collecting completed rating forms. For these experimenters, the trial run would serve as a rehearsal and would permit coordination of experimental procedures.

Experimenters are to use the trial run to make certain that they can recognize preselected rough and smooth sections of track in advance so that in the final run they can properly notify passengers of the approach of segments to be rated.

Experimenters are to make notes as to which habitability components can, or should, be measured, and which will be simply described. On completion of the trial run, these notes are to be reviewed. Formats can then be developed so that both experimenters and passengers can describe habitability during the experiment.

4.3.3.2 Captive Passenger Run

Prior to the test run, paid passengers will be instructed on use of the various rating formats. Procedures to be followed will be explained, including the use of color-coded armbands and matching response forms to enable experimenters to keep track of the subject subgroups. Information on demographic characteristics, trip purpose, prior experience, set, and attitude will also be collected at this time. The signal system to be used should be explained and demonstrated.

4.3.3.3 Signal System

The experimenter checking track position is to signal to the other experimenters, who will then repeat the signal for passengers in each coach.

Signal 1:	Bell rung--vibration event to be rated is about to be reached.
Signal 2:	Light on--during this time, passengers will pay attention to vibrations being experienced. (The number assigned to this vibration event on the rating sheet will also be held up by experimenter.)
Signal 3:	Light off, flag waved--rate the vibration event.

Prior to the trip, one person in each subgroup is to be designated to turn the recording equipment on at Signal 2, and off at Signal 3.

Since one purpose of this study is to determine the influence of coach and seat location, and the reliability of such influence, the following seat assignments will be made.

At the onset of the trip, passengers will be seated as follows:

	End	Middle
Coach 1	A (red)	B (green)
Coach 2	C (yellow)	D (white)

At a pre-specified time, Groups A and B, C and D are to exchange seats. Returning from Philadelphia, groups are to remain intact and will again exchange seats as indicated above.

4.3.4 ANALYSIS OF RESULTS

4.3.4.1 Verbal Descriptors--Obtained on Run from Washington to Philadelphia

Results should be analyzed to determine which components of vibration and habitability environments are the greatest contributors to overall evaluation of ride quality. Data from track geometry measurements can be used as a record of smooth track and segments of rough track encountered.

Working from the above records and the schedule actually made from Washington to Philadelphia, words used as descriptors in response to open-ended questions should be tallied in order to determine which words or adjectives are most frequently used to describe the various categories of vibration events as stimuli, and the extent to which they are consistently used by different passengers to describe the same events/vibrations.

Similarly, responses to lists of adjective descriptors provided for passengers to check are to be analyzed by event for consensus. The chi square statistic may be used to determine to what extent different aspects of vibration elicit different responses, and the extent to which passengers agree on adjectives describing vibration events.

4.3.4.2 Analysis of Data Obtained on Return Trip

Essentially, there are four major aspects in the analysis of passenger response regarding the comfort and acceptability of vibration, habitability and their components. Correlation of response data with concomitant physical measures of vibration and habitability components will allow the determination of the relationship between ride and ride quality.

1. Reliability of ratings. Preliminary tabulation procedures should be formulated to facilitate the determination of the reliability coefficient, which reflects the consistency of the comfort and acceptability ratings across subjects.
2. The same analyses will provide a test of subject ability to consistently discriminate between vibration events of varying roughness. (Hoyt's analysis of variance techniques should be used.) Duncan's multiple range and multiple F-tests may be applied to both comfort and acceptability rating means. Assuming both a substantial reliability and a significant F-value for differences between the means, further analyses can be undertaken.
3. Assuming that subjects can make discriminations, further analysis can be directed toward determination of the multiple relationships between vibration components and evaluation of ride quality. Multiple regression analysis can be employed to determine which subsets of vibration event measures best predict ride quality responses. Parallel analyses will be undertaken for habitability components and for combinations of vibration and habitability components. Canonical analysis techniques can be used to determine the relationships between sets of descriptive factors and sets of evaluative responses.
4. Determination of probable multiple relationships between demographic factors, coach, seat location, prior experience, set, etc., and ride quality evaluation.

The multiple regression analysis can be used to assess the effects of seat, location, coach, age of subject, etc., and habitability and vibration ratings upon each other and upon evaluations of ride quality. The complete factorial design of this experiment, as summarized in Table 4-5, will also allow an analysis of variance to be performed to investigate the possible existence of important interactions.

Hoyt's technique* yields an estimate of the inter-subject reliability (consistency across people) in making ratings or responding to the vibration events. Separate analyses would be performed for each response measure; i.e., for habitability components.

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*Johnson, Palmer, Statistical Methods in Research, Prentice Hall, Inc., Englewood Cliffs, New Jersey, 1950, pp. 134-136

Table 4-5. Summary of Factorial Experimental Design for Captive Passenger Setting

Subject	Vibration Events	Physical Value Vibration Events	Comfort Response Data	Overall Ride Evaluations	
	$E_1\ E_2$---E_N*	$E_1\ E_2$---E_N	E_1-----E_N	RQ	Control Variables as Desired
1	0 1 0 0 0 0 0	2 4 3 9 7 8	R_1--------R_N	RQ_{s1}	
2	0 0 0 0 1 0 0		R_1--------R_N		
3	0 0 0 0 0 0 1		R_1--------R_N		
N = 32					
$\overline{M}$	$\overline{M}\ \overline{M}\ \overline{M}\ \overline{M}\ \overline{M}\ \overline{M}$		$\overline{R}_1$--------$\overline{R}_N$		$\overline{M}$

*E_1 - E_x = Smooth ride segment

E_{x+1} - E_N = Rough ride segment

4.4 EXPERIMENTAL DESIGN FOR THE FARE-PAYING PASSENGER SETTING ON AN INTERURBAN TRAIN

This study would measure relationships between ride, habitability and operational factors, and ride quality (i.e., passenger evaluation of these factors) by fare-paying passengers on interurban trains. Objectives are of two types: substantive and methodological.

Substantive objectives are:

1. Collection of ride quality evaluations from samples of riders for various conditions and permutations of conditions common to U.S. railroads.
2. Concurrent measurement of vibration, habitability, and operational factors and subcomponents so as to correlate these with ride quality evaluations.

Methodological objectives involve:

1. Verification of topics/issues on which data should be collected for evaluation of the ride of any public transportation vehicle.
2. Establishment of an efficient set of procedures for measurement of V, H, and O and passenger perceptions of these.
3. Determining the extent to which evaluations by captive passenger studies can be used to predict ride quality evaluations by fare-paying passengers.
4. Providing a basis for forecasting passenger evaluations of rides aboard other types of vehicles, based on simulation and differences between V, H, and O in trains and in other vehicle types.

4.4.1 BACKGROUND

As nearly as we can determine from the literature search and from discussions with cognizant AMTRAK personnel, there have been no passenger surveys of the scope of that proposed here.

Previous studies have focused on one or two vibration and/or habitability components; for example, seating [8], noise and vibrations [80], or vibration only [20,38,47,49,75, and 76]. Passenger surveys (i.e., Wahmann and Fleischman [81]), have not included concomitant measurements of the physical components of vibration and habitability. Still other investigators have studied cost versus performance [35] or whether operational changes increase the use of trains [68]; here, there is no measurement of either passenger evaluations or train environment.

4.4.1.1 Problems: Natural Experimentation as an Approach

Several issues need to be resolved:

1. Information requirements: What do we want to know? What areas should be explored by questions? Areas have been developed and specific issues identified, based upon our literature review.
2. Ride quality interrogation formats: How shall questionnaires be constructed to obtain valid and reliable information from passengers? The captive passenger experiment, and that at NASA-Langley Research Center, will contribute to the development of questions and rating scales.
3. Information about ride: What measures of the physical environment (i.e., V, H, and O) are needed? When, and how, are these to be collected during the ride? The captive passenger study will provide answers to a number of these questions.
4. Sampling: How does one draw an adequate sample? There are potentially a great number of factors that may influence ridership and evaluations of ride quality. At the onset, we do not know how to sample from such variables as:
    a. Time of day
    b. Day of week
    c. Length of trip
    d. Express or local train
    e. Peak load; off-peak load
    f. Coach type and location
    g. Type of propellant (diesel, electric, turbo, etc.)
    h. Special-purpose vehicle (i.e., commuter, cross-country, autotrain)
    i. Factors specific to a geographic area
    j. Differences in railroads and services provided
    k. Aspects of the cross-country trips, such as time on train, different legs of trip, etc.

4.4.1.2 Summary

Information requirements have been fairly well specified. Experiments I and II will contribute to the development of rating scales, as well as to the determination of how the physical parameters that describe ride can be efficiently measured and summarized. The primary issues, not resolved by prior work, have to do with adequately sampling passengers across the many parameters or conditions in which rides occur.

Tens of thousands of passengers ride U.S. interurban trains 24 hours a day. Environmental conditions vary with respect to the many sampling parameters listed above, as well as others, along with variations in factors developed in this study--passenger demography, trip purposes, passenger expectations, V, H, and O, etc. To evaluate the impact of these differences, we suggest applications of the concept of natural experimentation.

4.4.2 GENERAL EXPERIMENTAL PLAN

Natural experiments--sometimes called operational or ethological experiments--can be applied in complex situations where many observable phenomena are occurring repeatedly, and wherein it is impossible or impractical to exercise controls.

Data collection instruments can be applied to record these variations as they occur. After sufficient data are collected, associations between factors can be determined. In this instance, passenger ride quality evaluations are dependent variables; tests of association can be run between other factors or conditions and their combinations, and passenger evaluations.

Assessment of ride quality as evaluated by fare-paying passengers lends itself readily to natural experimentation. Stimulus and response measurements are relatively easy. A stream of passengers is continuously available. Most conditions occur and recur with sufficient frequency that substantial numbers of similar and different conditions can be recorded and compared with ride quality evaluations in tests of association.

The recommended fare-paying passenger experiment would involve a trip from Washington to Philadelphia and return. This is the same trip as that described in the proposed experiment with captive passengers which was performed to check out the data forms, procedures, etc. Subjects of interest this time are fare-paying passengers.

We would recommend, however, embedding a revised version of the captive-passenger experiment into this ride--a version which profits from what was learned during the first captive passenger study--to ascertain the relationship between evaluations by captive, or paid, passengers and evaluations by fare-paying passengers riding on the same train.

This approach has several advantages:

1. It will provide a substantial body of information on almost all the sampling parameters. Sufficient data will be obtained to establish relationships between parameters and interactions associated with ride quality evaluations across major passenger-carrying railroads of the United States.
2. The surveys would not be excessively costly. Primary costs involve developing valid and reliable data collection tools, and developing procedures to assure that comprehensive measures of ride and ride quality are obtained.
3. The gradual buildup will allow instruments to be refined after the first trip, and procedures to be extended by steps to cover longer trips.

4.4.2.1 Selection of Subjects

All passengers aboard sampled trains are the subjects. Information on demographic characteristics, trip purpose, prior experience, set, attitude, and duration of trip (through passenger designation of points of origin and destination) will be collected. In addition, subjects will be provided with forms, developed in the captive passenger study to permit evaluation and rating of V and H. Forms for passenger evaluation of O will be developed prior to the study.

4.4.2.2 Railway Vehicle Designation

Railways carrying the most passengers in the northeast corridor and cross-country will be subjects of study. Variations in carriers, coach types, and services provided will occur naturally and will be described.

4.4.2.3 Measurement of Vibration, Habitability, Operational Factors

Two of the FRA Portable Ride Quality Packages would be used to periodically measure the vibration environment. One will be placed at the center of a coach, one at the end. Habitability and its components will be measured or described, for each coach of the sampled trains, by data collection team members using structured checklists. Certain operational factors (such as schedule maintenance) will also be described/measured by the data collection team. Other operational data will be collected if feasible. Provisional determination of what operational data can be collected will be made prior to, and modified during, the first trip.

4.4.2.4 Methodology

In developing a model to assess the influence of various train features and conditions, the factors believed to contribute most to the passenger evaluation of ride quality need to be included. As a starting point, some factors considered to have a major influence are listed in Tables 4-6 and 4-7 along with designation of the supplier/collector of the necessary information for each factor. Specific questionnaires will be developed based on these factors and the results of prior research. Rating scales used will be those previously tested and modified.

Table 4-6. Information Required for Fare-Paying Passenger Studies

Obtained from Passengers	Recorded by Team Members
* 1. Demographic, psychological data	1. Periodic measurement of vibration sample
* 2. Trip purpose	2. Evaluation of habitability for each coach--including periodic count of standees.
3. Trip length, time on train, point of origin and destination	3. Operational factors--evaluation or recording (crowdedness, cleanliness)
4. Attitude toward mode, comparison of modes	4. Train schedule--whether on schedule, ahead, behind.
5. Time of day, day of week	5. Periodic measurement of speed
6. Prior experience	6. Time of day and day of week
* 7. Comfort, response to vibration and components	7. Type of train, chart of coach order
* 8. Rating of habitability and components	8. Type of coach, number per type and location of each
* 9. Rating of operational factors	9. Area of country, terrain features
10. Overall comfort	10. Railways used, point of change
11. Satisfaction, acceptability of mode	11. Services provided by each railway
12. Comments on any/all aspects and phases of trip	12. Comments on problems, concerns, incidents, anything felt to be relevant to study

*See Table 4-7 for detailed list of factors to be studied.

Table 4-7. List of Factors to Be Studied

1. <u>Demographic Data</u>:

   Age, sex, income level, occupation, urban, suburban, rural, physical disability

   <u>Psychological Data</u>:

   Set, attitude, expectations

2. <u>Trip Purpose</u>:

   To work or business trip

   Non-work -- Personel
   Social
   Family
   Recreational/vacation

3. <u>Vibration Components</u>:

   Oscillation, jerk, surge, sway, curve traversal, crossover, induced vibration

4. <u>Habitability Factors</u>:

   Noise, seating, interior lighting, windows, temperature, air quality, decor, handholds, baggage accommodations, entrance/exit, toilet facilities

5. <u>Operational Factors</u>:

Convenience:	Schedule, location of points of origin and destination, accessibility
Cost:	Fare and trip time
Time-related factors:	Waiting time, delays, transfers to same or other modes

   Reliability

   Safety

   Cleanliness

   Congestion: on vehicle and in terminal

   Personal Services

4.4.2.5 Data Collection Team

Massive amounts of data, constant record keeping, questionnaire distribution, etc., during a sampling of passenger ride quality evaluations require the use of two three-man teams. Each team would have sole responsibility for data collection storage, etc., over specified portions of the trip. However, for training purposes, all team members would function during test trips.

Two three-person teams should man the train. They would provide backups for one another, but within a team each would perform certain assigned functions as listed in Table 4-8. All members of the team would be provided with sheets on which to independently record their impressions of passenger likes and dislikes, conditions influencing evaluations, problems, perturbations of any sort, etc. During the test trips, members of the team would be asked to maintain a log containing comments on procedures, problems occurring, etc.

4.4.2.6 Data Collection Plan: Organization

A document should be drawn up describing the data collection plan. Section I of the test plan would describe the purpose of the study, how this purpose is translated into procedures and formats for data collection, plus issues and questions that information to be collected will bear on, and hopefully answer.

Section II would describe specific data collection functions to be performed, referenced to data collection instruments, versions of which would be appended. This section would tell how these functions are performed during the ride.

Section III would describe the duties of members of a three-man data collection team, and how duties are to be accomplished. Responsibilities for coordination among members and backup duties will be indicated. As an example:

Table 4-8. Information Collection, Maintenance Tasks

	Surveyers 1, 2 and 3 Functions	Correlation of data collection effort to specific train, coaches	Measurement of V, H, O	Passenger survey of antecedent V_c H_c O_s info
1	Team leader passenger survey	Assures proper forms go to each coach. Assumes data collection.	Evaluates crowding and V, H, O and components	Responsible for handing out to all passengers. Collector of forms. Assisted by 2, 3.
2	Maintenance of forms, omitting data collection	No. coach, coach position coded to survey forms	Checks schedule for collection to assume completed forms are in/out on schedule	Checks no. passengers. No forms.
3	Collection of data V, H, O	Identity of RR train, schedule, staffing of train, whether driver, sleeper, etc.	Periodic recording of V	- - -
			Ratings of coaches	
			Info RR; train schedules	

1. A team member, possibly the team leader, collects data on vibration, habitability and operational factors, and maintains a trip log.
2. A team member is responsible for collection of data from passengers.
3. A team member is responsible for maintenance of data formats and the proper identification and filing of completed data forms.

Procedures established would permit team members to call on each other for assistance during peak-load times in certain task areas.

Section IV of the test plan would provide a time-line schedule for each planned trip, indicating specifically what data are to be collected by each team member, forms used and times of collection during trips.

4.4.3 ANALYSIS OF RESULTS

The nature of the study requires the use of descriptive statistics for comparing ride quality evaluations and the factors which may, or may not, influence them. Passenger response to V, H, and O factors should be tabulated. Those which seem to have a major influence on global V, H and O evaluation and judgments of overall ride quality would then be identified through an analysis of variance of the responses of ride acceptability. Statistically important factors would then be examined for clues to environmental or operational reasons behind the evaluation made.

Statistical tests of association between various measures will be run (for example, responses during eastward versus westward travel). Either partial correlations or analysis of variance/covariance is applicable.

Procedures similar to those developed for the captive, or paid, passenger studies will be employed to determine which factors or combinations of factors most influence passenger ride quality evaluation.

Essentially, there are four major aspects to the analysis:

1. Reliability of the ratings. Preliminary tabulation procedures will be formulated to facilitate the determination of reliability coefficients reflecting the consistency of passenger ratings. Hoyt's analysis of variance technique will again be used.
2. Duncan's multiple range and multiple F-tests will be applied to comfort and acceptability rating means. Assuming a substantial reliability and significant F-value for differences between the means, further analyses can be undertaken.
3. Determination of the multiple relationships between various components and ride quality. Multiple regression analysis will also be employed to determine which subsets of components best predict ride quality responses. Components from all dependent variables will be used: sampling parameters, passenger characteristics and natural variations plus direction of travel. New coefficients for the predictor equation will thus be developed.
4. Factors and factor combinations influencing evaluation. Analysis of variance and covariance techniques will be used to determine the factors and factor combinations which most influence ride quality evaluation. Here again, F-tests will indicate the significance of contribution of each factor.

4.5 GENERALIZED EXPERIMENTAL DESIGNS FOR THE CAPTIVE PASSENGER SETTING

The experimental design that we have recommended for interurban trains would apply to that specific vehicle. This experimental design can also be used as a model for studies of paid passengers aboard other operational vehicles. Some adaptations of terminology would be required to apply this design to a different vehicle and the details of the experiment should be modified to incorporate administrative improvements based on experience in conducting research in this setting. However, the general approach and methods should be relevant across transportation modes and vehicles.

The specific experimental design that we have recommended for interurban trains must be considered exploratory rather than comprehensive in nature. Many of the objectives of this experiment are methodological in nature rather than being specifically oriented to the ride quality of trains. Designs of experiments for the comprehensive evaluation of the ride quality of a particular transportation mode must be based on the careful consideration of these factors. In addition, the experimental designs must consider the total number of factors which must be investigated and the most efficient way to perform the required experiments.

The efficient design of experiments is traditionally considered in the terms of agricultural research for which the techniques were developed. The textbook explanation of the various techniques groups the experimental factors in terms of blocks, plots, and treatments. The design of experiments for the captive passenger setting can be based on these experimental procedures if a conceptual translation of terminology is performed.

Blocks--Corresponds to a vehicle or similar vehicle having the same structural, habitability, and operational characteristics.

<u>Plots</u>--Corresponds to individual passengers or to groups of passengers which are homogeneous with respect to demographic, trip purpose, and expectation factors.

<u>Treatments</u>--Corresponds to differences in ride resulting from different guideway characteristics or from specific changes in a vehicle's dynamic response characteristics.

The design of efficient experiments for the investigation of ride quality requires the identification of important factors. The specific experimental design to be used is then based on analyses of the interrelationships which exist among these factors and on the required accuracy of the results.

4.5.1 IDENTIFICATION OF MAJOR FACTORS AFFECTING RIDE QUALITY EVALUATIONS

The various factors affecting the ride quality of different transportation modes have been determined from a thorough review of the literature. The results of the literature review are summarized in Chapter 2 and in Appendices I through IV.

For purposes of experimental design, the important factors for each transportation mode are listed in Table 4-9 in a form consistent with the factor groupings used in experimental designs as defined above. The design of additional experiments should review the results of the experiments that we have proposed in order to identify those factors which are listed but are found not to be correlated with ride quality evaluations. Greater precision in the experimental designs may be achieved by refining these lists of important factors and their interactions.

Table 4-9. Important Factors Affecting Perceived Ride Quality in the Captive Passenger Setting

4-9a. Rail Rapid Transit

Vehicle Factors	No. of Treat-ments	Subject Factors	No. of treat-ments	Guideway and Vibration Factors	No. of treat-ments
Temperature: Air-conditioned; not air-conditioned (outside range of 65-75 degrees)	2	Sex: male; female	2	Design geometry: Tangent Curved	2
Noise level: Greater than 90 dba Less than 90 dba	2	Age: Equal partition of expected ridership	2 or 3	Surface: Welded rail Bolted rail	2
Seat Orientation: Facing forward Facing backward Facing sideways Passenger forced to stand	4	Prior experience with mode: Frequent (daily) Infrequent	2	Support structure: Surface construction on ballast Elevated construction Subway construction	3
Seat Position: In center of car Over trucks	2	Normal mode choice: Bus Automobile Rail rapid transit	3	Irregularities: None Switches Track cross-over	3
Provision for package storage: Storage racks No storage racks	2	Expectation prior to ride: Vibration important factor Vibration relatively unimportant	2	Frequency of stops: Local Express service	2
		Storage requirements: Passenger carrying packages Not carrying packages	2		
TOTAL	64	TOTAL	96 or 144	TOTAL	72

Table 4-9. Important Factors Affecting Perceived Ride Quality in the Captive Passenger Setting

4-9b Interurban Trains

Vehicle Factors	No. of Treat-ments	Subject Factors	No. of treat-ments	Guideway and Vibration Factors	No. of treat-ments
Power: Onboard (RDC, turbo-train) Electrified (Metroliner) Non-powered (separate tractive unit)	3	Sex: male; female	2	Design geometry: Tangent Curved	2
		Age: equal partitions of normal ridership	2 or 3		
Body construction: Underframe Integral stressed skin	2	Prior experience with mode: Frequent (one trip per month) Infrequent	2	Surface: Welded rail Bolted rail	2
Seat orientation: Facing forward Facing sideways Facing backward	3	Expectation prior to ride: Vibration important ride factor; Vibration relatively unimportant	2	Quality of geometry FRA class 4 FRA class 4	2
Seat position: Center of car Over wheels	2	Trip duration Under 4 hours Over 4 hours	2	Irregularities: None Switches Track cross-overs	3
		Normal mode choice for trip of this length: Train Bus Plane Automobile	4	Wheel condition: New Worn (coned or out-of-round)	2
TOTAL	36	TOTAL	128 or 192	TOTAL	48

Table 4-9. Important Factors Affecting Perceived Ride Quality in the Captive Passenger Setting

4-9c. Magnetically Levitated Vehicles

Vehicle Factors	No. of Treat-ments	Subject Factors	No. of treat-ments	Guideway and Vibration Factors	No. of treat-ments
Type of suspension: Attractive Repulsive	2	Sex: male; female	2	Design geometry: Tangent Curved	2
Power source: Onboard External to vehicle	2	Age: equal partitions of normal ridership	2 or 3	Support structure: Surface Elevated (pier and beam)	2
Seat orientation Facing forward Facing backward Facing sideways	3	Prior experience with mode: Frequent (one trip per month) Infrequent	2	Accuracy of guideway surface: High quality Marginally acceptable quality	2
Seat position: Center of car End of car	2	Expectation prior to ride: Vibration important ride factor; Vibration relatively unimportant	2		
		Trip duration: Under 4 hours Over 4 hours	2		
		Normal mode choice for trip of this length: Train Bus Plane Automobile	4		
TOTAL	24	TOTAL	128 or 192	TOTAL	8

Table 4-9. Important Factors Affecting Perceived Ride Quality in the Captive Passenger Setting

4-9d. Monorail (steel wheel on steel rail)

Vehicle Factors	No. of Treat-ments	Subject Factors	No. of treat-ments	Guideway and Vibration Factors	No. of treat-ments
Temperature: Airconditioned Not airconditioned (outside range of 65-75 degrees)	2	Sex: male; female	2	Design geometry: Tangent Curved	2
		Age: equal partition of expected ridership	2 or 3		
Noise level: Greater than 90 dba Less than 90 dba	2	Prior experience with mode: Frequent (daily) Infrequent	2	Support structure: Stiff beams between close-set piers Flexible long beams	2
Seat orientation: Facing forward Facing sideways Facing backward Passenger forced to stand	4	Normal mode choice: Bus Automobile Rail rapid transit	3	Sway control: Good Poor	2
Seat position: In center of car Over trucks	2	Expectation prior to ride: Vibration important factor Vibration relatively unimportant	2	Irregularities: None Switches	2
Provision for package storage: Storage racks No storage racks	2	Storage requirements: Passenger carrying packages Not carrying packages	2	Frequency of stops: Local service Express service	2
TOTAL	64	TOTAL	96 or 144	TOTAL	32

Table 4-9. Important Factors Affecting Perceived Ride Quality in the Captive Passenger Setting

4-9e. Tracked Air Cushion

Vehicle Factors	No. of Treat- ments	Subject Factors	No. of treat- ments	Guideway and Vibration Factors	No. of treat- ments
Power: Onboard (RDC, turbo-train) Electrified (Metroliner) Non-powered (separate tractive unit)	3	Sex: Male; female	2	Design geometry: Tangent Curved	2
Car body construction: Underframe Integral stressed skin	2	Age: equal partitions of normal ridership	2 or 3	Support structure: On ground Elevated	2
Seat orientation: Facing forward Facing sideways Facing backward	3	Prior experience to ride: Frequent (one trip per month) Infrequent	2	Accuracy of surface: High quality Marginal quality	2
Seat position: Center of car Over wheels	2	Expectation prior to ride: Vibration important ride factor Vibration relatively unimportant	2		
		Trip duration: Under 4 hours Over 4 hours	2		
		Normal mode choice for trip of this length: Train Bus Plane Automobile	4		
TOTAL	36	TOTAL	128 or 192	TOTAL	8

Table 4-9. Important Factors Affecting Perceived Ride Quality in the Captive Passenger Setting

4-9f. Ground Effect Machine

Vehicle Factors	No. of Treat-ments	Subject Factors	No. of treat-ments	Guideway and Vibration Factors	No. of treat-ments
Power: Gas turbine Reciprocating engine	2	Sex: male; female	2	Surface: Water--smooth Water--rough waves Land--unimproved path Land--paved guideway	4
Noise level: Greater than 90 dba Less than 90 dba	2	Age: equal partitions of normal ridership	2 or 3	Speed: Less than 30 mph Greater than 30 mph	2
Ride control: Servo-controlled No responsive control	2	Prior experience with mode: Frequent (one trip per month) Infrequent	2		
Seat orientation: Facing forward Facing sideways	2	Expectation prior to ride: Vibration important ride factor Vibration relatively unimportant	2		
Seat location: Next to window Interior	2	Trip duration: Under 4 hours Over 4 hours	2		
		Normal mode choice for trip of this length: Train Bus Plane Automobile	4		
TOTAL	32	TOTAL	128 or 192	TOTAL	8

Table 4-9. Important Factors Affecting Perceived Ride Quality in the Captive Passenger Setting

4-9g. Personal Rapid Transit

Vehicle Factors	No. of Treat- ments	Subject Factors	No. of treat- ments	Guideway and Vibration Factors	No. of treat- ments
Passenger capacity: Six or less Greater than six	2	Sex: male; female	2	Guideway: Steel wheel on steel rail Rubber tire on paved guideway	2
Power: Onboard Electrified	2	Age: equal partition of expected ridership	2 or 3	Support structure: Elevated Surface	2
Seat orientation: Facing forward Facing sideways Facing backward Standing	4	Normal mode choice: PRT Intraurban bus Automobile	3	Frequency of stops: Local service, frequent stops for passenger access Frequent stops for traffic, no passenger access Express to destination	3
Provision for package storage: Storage racks No storage racks	2	Storage requirements: Carrying packages Not carrying packages	2		
		Expectation prior to ride: Vibration an important factor Vibration relatively unimportant	2		
TOTAL	32	TOTAL	48 or 72	TOTAL	12

Table 4-9. Important Factors Affecting Perceived Ride Quality in the Captive Passenger Setting

4-9h. Dual Mode

Vehicle Factors	No. of Treat-ments	Subject Factors	No. of treat-ments	Guideway and Vibration Factors	No. of treat-ments
Temperature: Air-conditioned; not air-conditioned (outside range of 65-75 degrees)	2	Sex: male; female	2	Design geometry: Tangent Curved	2
		Age: Equal partition of expected ridership	2 or 3	Surface: Welded rail Bolted rail Pavement (express bus mode)	3
Noise level: Greater than 90 dba Less than 90 dba	2	Prior experience with mode: Frequent (daily) Infrequent	2	Support structure: Surface construction on ballast Elevated construction Subway construction	3
Seat Orientation: Facing forward Facing backward Facing sideways Passenger forced to stand	4	Normal mode choice: Bus Automobile Rail rapid transit	3	Irregularities: None Switches Track cross-over	3
Seat Position: In center of car Over trucks	2	Expectation prior to ride: Vibration important factor Vibration relatively unimportant	2	Frequency of stops: Local Express service	2
Provision for package storage: Storage racks No storage racks	2	Storage requirements: Passenger carrying packages Not carrying packages	2		
TOTAL	64	TOTAL	96 or 144	TOTAL	108

Table 4-9. Important Factors Affecting Perceived Ride Quality in the Captive Passenger Setting

4-9i. Interurban bus

Vehicle Factors	No. of Treatments	Subject Factors	No. of treatments	Guideway and Vibration Factors	No. of treatments
Temperature: Within range 65-75°F Outside of range of comfort	2	Sex: male; female	2	Design geometry: Straight road Frequent curves	2
Power: Gas turbine Reciprocating engine	2	Age: equal partitions of normal ridership	2 or 3	Pavement type: Asphalt (no joints) Concrete (slab joints)	2
Seat position: Center Over wheels	2	Prior experience with mode: Frequent (one trip per month) Infrequent	2	Pavement condition: Smooth Patched Potholes	3
Seat location: Window Aisle	2	Expectation prior to ride: Vibration important Vibration relatively unimportant	2	Vehicle suspension maintenance: New shock absorbers Worn shock absorbers	2
		Trip duration: Under 4 hours Over 4 hours	2		
		Normal mode choice for trip of this length: Train Bus Plane Automobile	4		
TOTAL	16	TOTAL	128 or 192	TOTAL	24

Table 4-9. Important Factors Affecting Perceived Ride Quality in the Captive Passenger Setting

4-9j. Urban Bus

Vehicle Factors	No. of Treat-ments	Subject Factors	No. of treat-ments	Guideway and Vibration Factors	No. of treat-ments
Temperature: Within range 65-75°F Outside range of comfort	2	Sex: male; female	2	Design geometry Straight road Frequent turns	2
Power: External (electrified) Gas turbine Reciprocating engine	3	Age: Equal partition of expected ridership	2 or 3	Pavement type: Asphalt (no joints) Concrete (slab joints)	2
Seat Orientation: Facing forward Facing sideways Standing	3	Prior experience with mode: Frequent (daily) Infrequent	2	Pavement condition: Smooth Patched Potholes	3
Seat position: Center Over wheels	2	Normal mode choice: Bus Automobile Rail rapid transit	3	Frequency of stops: Local (every block) Express	2
Seat location: Aisle Center	2	Expectation prior to ride: Vibration important factor Vibration relatively unimportant	2		
Provision for package storage: Yes No	2	Storage requirements: Passenger carrying packages Not carrying packages	2		
TOTA:	144	TOTAL	96 or 144	TOTAL	24

Table 4-9. Important Factors Affecting Perceived Ride Quality in the Captive Passenger Setting

4-9k. Moving Belt Transport

Vehicle Factors	No. of Treat-ments	Subject Factors	No. of treat-ments	Guideway and Vibration Factors	No. of treat-ments
Speed change at entrance and exit: Low Relatively high	2	Sex: male; female	2	Design geometry: Straight, level Straight, slope Curved, level Curved slope	4
		Age: Equal partition of expected ridership	2 or 3		
Seating: Seats available Standing	2	Length of ride: Less than 4 minutes More than 4 minutes	2	Surface of belt: Steel grid Composition tile Carpet	3
Provision for packages: Yes No	2	Storage requirements: Passenger carrying packages Not carrying packages	2	Frequency of access: Intermittent Only at ends	2
Width of belt: Single passenger Two passengers side by side	2	Physical disability: None Restricted mobility (cane, crutches, etc.)	2		
TOTAL	16	TOTAL	32 or 48	TOTAL	21

Table 4-9. Important Factors Affecting Perceived Ride Quality in the Captive Passenger Setting

4-91. Passenger in Automobile

Vehicle Factors	No. of Treat- ments	Subject Factors	No. of treat- ments	Guideway and Vibration Factors	No. of treat- ments
Temperature control: In comfort range Out of 65-76°F range	2	Sex: male; female	2	Roadway geometry: Straight Frequent turns	2
Seat location: Front Back side Back center	3	Age: equal partitions of expected ridership	2 or 3	Surface of roadway: Asphalt (no joints) Concrete (slab joints)	2
Size of vehicle Standard Compact Subcompact	3	Prior experience with mode: Daily Less often	2	Roadway surface condition: Smooth Patched Potholes	3
		Normal mode choice: Bus Automobile Rail	3	Frequency of traffic interactions: Express Frequent changes of speed and lane	2
		Expectation prior to ride: Vibration an important negative factor Vibration not important	2		
		Trip duration: Less than 1 hour Greater than 1 hour	2		
TOTAL	18	TOTAL	96 or 144	TOTAL	24

4.5.2 OPTIMIZATION OF EXPERIMENTAL DESIGNS

The complete investigation of the effects of each of the important factors listed in Table 4-9 and the interaction of these factors is clearly impractical. A complete factorial design which could test all of the interactions of the listed factors would require tens of thousands of subject evaluations of ride quality, and the experiment would then need to be duplicated several times to allow for estimation of intersubject differences among subjects who have the same demographic characteristics.

The use of complete factorial experiments is required where the interaction between factors is expected to have an important influence on the observed results. However, for the captive passenger setting, although many factors are listed in Table 4-9 as having possible influence on the evaluation of ride quality, it is unlikely that all of these factors are really important. It is even less likely that all of the interactions among factors are important.

A considerable savings in effort can be achieved if only the effects of the main factors and their low-level (or pair-wise) interactions are investigated. This goal of experimental efficiency can be achieved through the use of various specialized experimental designs such as partial factorial, incomplete block, and Yonden square plans. The details of these experimental plans and the required analysis procedures for each plan are described in detail in the literature [80]. In the following sections, we discuss the application of these procedures to the problem of optimizing the investigation of ride quality in the captive passenger setting.

4.5.2.1 Identification of Main Ride Quality Factors Using Partial Factorial Experimental Design

The captive passenger setting implies a certain procedure for the way the experiment is to be run: a given vehicle is run over a specified route at a specified speed resulting in (nearly) reproducible ride conditions. Various segments of the ride are evaluated by passengers who are paid to ride the vehicle. The subjects differ in demographic characteristics and sit in different assigned places in the vehicle.

The investigation of the interactions of all the demographic and seating factors alone may require more subjects than can be accommodated on the vehicle. However, the measurement of the responses of subjects representing only a fraction of the total number of combinations of factors is required in the investigation of the main effects of the parameters. This fraction must consist of subjects having carefully specified combinations of the factors to be investigated. If each factor exists at two levels (i.e., if the subjects are partitioned on the basis of sex [M,F], age [old, young], location in vehicle [middle, end], etc.), only one-eighth the total number of subjects are required to measure the main effects of the factors in comparison to a full factorial experimental design. If all of the second order interactions are to be investigated as well, the savings still amount to one-half the number of subjects required for a full factorial experiment.

The investigation of the influence of demographic factors on ride quality requires careful selection of subjects. The particular combinations of factors which are required for each subject are specified as part of a partial factorial experimental design. The required combinations have been calculated for a great number of combinations of factors which are controlled at either two or three levels. The details of these experimental designs are available from the literature [81,82].

4.5.2.2 Use of Incomplete Block Experimental Designs

It may be that all of the subjects cannot be accommodated during a single test run. There may not be enough seats to accommodate them all. Alternatively, it may be desired to move the subjects around in the vehicle to have them experience different starting conditions during a second test run.

If several test runs are required, the ride conditions can be expected to be similar, but not necessarily exactly the same. The effects of these ride differences require the use of the experimental procedure known as incomplete block designs. The choice of the particular design depends on the accuracy of the measurements of ride quality, and on the amount of difference in the ride of the various test runs.

Two main types of incomplete block designs can be used in the situation where multiple test runs are required. The balanced incomplete block design has the advantage that the interrun differences are measured with precision, and that the analysis procedure is relatively simple.

If the differences between runs are small compared to the precision of estimating the quality of each ride segment of each run, a chain block design will allow the estimation of a greater number of factors with fewer subjects than will the balanced incomplete block design. This efficiency in performance of the experiment is gained only at the cost of more complex analysis procedures and a loss of precision in the estimation of interrun differences.

Detailed descriptions of the requirements, analysis procedures, and relative advantages of these experimental designs are available from the literature [53, Ch. 13, p. 6].

4.5.2.3 Experimental Designs for the Investigation of the Relative Rides of Several Vehicles

It may be anticipated that the investigation of ride quality will require the evaluation of the rides of several vehicles of a single transportation mode, and that the ride quality investigation of each vehicle may require several test runs. Several experimental designs are available which allow for estimation of the effects of the major factors and the effects of intervehicle and interrun differences with a minimum number of subjects.

Latin Square experimental designs are probably the best known of the designs which allow efficient investigation of the effects of a number of independent parameters in a single set of experimental runs. These designs would probably be of little use in the investigation of ride quality as they would only be applicable where the number of vehicles, number of runs per vehicle, and number of important demographic factors are all the same.

The Youden Square plans are a generalization of the Latin Squares, and may be used where the number of runs differs from the number of vehicles and the number of factors. Unfortunately, satisfactory Youden Square plans exist for only a limited number of combinations of factors, and the analysis of the results from this type of experiment is rather complex.

A complete description of the available experimental designs for particular complex experimental requirements is felt to be premature at this point. The consideration of the details of the designs should be left until after a preliminary investigation of ride quality has identified the major factors which must be considered and has answered some of the methodological questions which presently exist.

At such a time that a comprehensive investigation of the ride quality of several vehicles is to be planned, the experimental designs should be based on a thorough review of the available literature and on the advice of a professional statistician.

4.6 EXPERIMENTAL DESIGNS: RECAPITULATION OF PRINCIPLES

The three experimental designs described in this chapter may serve as prototypes for experimental designs to be used for the study of other transportation concepts and vehicles. Several methodological assumptions are inherent in the suggested approach. The most important is that, in view of the scope of the research program, experiments are designed so we can learn as we go. Initial research designs serve several purposes:

Substantive

The substantive purpose is to determine what correlates with what; i.e., for a given vehicle, what ride parameters correlate with ride quality and to what extent. Until this is known, it is not possible to talk meaningfully about recommendations to design engineers that would improve ride quality. Since the important factors have not previously been investigated in detail, complete factorial experiments are required so that interaction of parameters can be identified. As we learn which stimulus parameters correlate with ride quality, we may wish to study these in greater detail, discarding for future studies those that are demonstrably unimportant. As we learn which interactions among factors are not important, we may improve the efficiency of captive passenger studies through the implementation of partial factorial experimental designs as required to investigate only the main factors.

Another substantive area to be explored as a basis for future designs is that of functional associations between passenger demography, trip purpose, etc., and ride quality evaluations. Stable associations, if found, have implications for sampling of passengers in future studies.

Methodological

In view of the many vehicles to be studied, development and refinement of methodology are perhaps more important in these first studies than collection of substantive information about one vehicle. This involves ride measurement, applying psychometric methods to the measurement of ride quality and correlating measures of ride and ride quality. Here on the response side, measurement approaches are not well developed. For example, we do not well know what terms subjects use to describe various aspects of vibration, nor how many discriminable levels of comfort there are.

Administrative

A third area in which knowledge and procedures need to be developed is in efficient administration of instruments that concurrently measure stimulus and response. Since we do not yet know just what vibration parameters and passenger perceptions to measure, or precisely how to measure passenger responses, efficient and practical administrative procedures cannot be set forth with confidence.

The most important things to be learned from the initial designs are related to tactics and techniques--essentially how to develop the most relevant and incisive experimental design for a particular study. Far more important in view of the broad objectives of this research program is that what is learned in initial studies be used to reassess the research strategy. By strategy, we mean development of sets of experimental designs such that findings within and between sets can be related. Examples of sets would be: all designs for a given vehicle, or all designs for a particular setting.

Logical requirements for integrated sets of experimental designs deserve more early attention than do requirements for precision and rigor of a particular design. Mistakes or omissions in single designs are more readily correctible, usually by pretests of designs before final administration or after data are inspected and analyzed.

4.6.1 APPLICATIONS OF RESEARCH STRATEGY: EXAMPLES

Early experiments are recommended for the simulator setting. Experimenters have studied ride quality assuming that response to vibration in simulators is related to response to vibration by fare-paying passengers aboard operational vehicles. Certainly, if great vibration excursions are used in simulators, and if rides in operational vehicles are found that are sufficiently rough, responses in these two settings must correlate. However, it is our belief, based on literature review, that the relationship between ride and ride comfort and acceptability has not been established <u>within the limits of vibration environments characteristic of vehicles people pay to ride on</u>. This is not to underplay the need for more knowledge of human response to vibration; there is, however, the question of the value of such knowledge to the pragmatic objectives of this study.

If, as a result of the implementation of the three designs, little relationship is found between responses to vibration in simulators and evaluations of comfort by fare-paying passengers subjected to the vibrations in METRO (we regard the probability of such a finding as low to moderate), different lines of inquiry would be warranted. One approach might be to subject simulator subjects to long vibration experiences rather than pairs of 8 or 10 second patches recommended in experiments outlined in this chapter. The literature does rather consistently show relationships between intensity of vibration and onset of fatigue; this is reflected in ISO standards. This factor may also require investigation to relate simulation results to responses of fare-paying passengers with some confidence.

Alternatively, it is not inconceivable that, based on information from early experiments, designs should focus on research areas rather different from--or in addition to--those for which we have developed designs. For example, it might be found that passenger set/expectations can predict ride quality evaluations better than predictive equations developed from simulator experiments. Such a finding would indicate greater attention to set/expectations and their attitudinal correlates. Whatever the findings, the overall program goal is to identify and demonstrate physical correlates or ride quality in support of useful vehicle ride specifications. This goal must determine research direction and modifications thereof.

4.6.2 CONCLUSIONS

In spite of some hundreds of studies extant which directly or indirectly relate to ride quality, what has been learned is modest.

Implementation of the three designs presented can provide much needed information about research technique, tactics of experimental design, administration of studies and research strategy. This information, critically reviewed, may call for shifts of research direction. It may require that priority be given to new research designs rather than to those outlined here. Meanwhile, incoming information will contribute to the formulation of more incisive tactics, more precise measurement techniques, and to more efficient administration of experiments for evaluation of ride quality of present and future vehicles, prototypes, and transportation concepts.

5. DEVELOPMENT AND TESTING OF PSYCHOMETRIC SCALES

The techniques used to measure a subject's evaluations of a ride must be based on the requirements and limitations of the experimental setting as follows. Simulator experiments measurements of subject's evaluations have been quite effectively obtained by a psychological technique comparing pairs of rides. In the captive passenger setting and the fare-paying passenger setting, the ride presentation format cannot be so completely controlled, and measurements of the passenger's evaluation of a ride must be obtained through the use of psychometric rating scales.

The evaluation of the results obtained from the use of such psychometric scales presents conceptual difficulties not encountered in the evaluation of matched pair preference ratings. Hypotheses concerning evaluative criteria and the more complex evaluative processes are not as well defined as are hypotheses about psychophysical processes.

In general terms, psychometric rating scales are used to obtain symbols that are related to the property being evaluated. For example, if a ride is evaluated in terms of comfort, a "comfort scale" would have a monotonic relationship to the comfort evaluation, and a one-to-one relationship could be established between "comfort" and "comfort scale ratings." Two separate problems are involved in establishing this equivalence. The first problem concerns establishing the relationships between the end points of the scale and the equivalent evaluations of comfort. The second problem involves establishing an equivalence between units on the scale and changes in comfort. These are the practical problems arising from the concepts of homogeneity and mathematical structure of a psychometric scale.

The success of any ride quality investigation will depend on the validity of the measurements of passenger evaluations of the ride. Therefore, it is of critical importance that the experiments be based on the use of valid and tested psychometric scales. The choice of the scales to be used must result from an evaluation of their structure and an experimental investigation of their properties.

5.1 EVALUATIVE CRITERIA FOR PSYCHOMETRIC SCALES

The usefulness of any psychometric scale for measuring ride quality will depend on its validity, homogeneity, and mathematical structure. Any scale used to measure ride quality must be evaluated with respect to these properties.

5.1.1 SCALE VALIDITY

The property or parameter to be measured by a scale is established by the words used to describe the ends of the scale and the intervening points along the scale. Psychometric scales defined by words may be unipolar, where the scale is defined by the magnitude of a single property or word; or bipolar, where the ends of the scale are defined by different words. A unipolar scale for discomfort would have its ends defined by "zero discomfort" and "maximum discomfort," A bipolar scale for comfort would have the ends defined as "comfortable" and "unpleasant."

Validity is achieved when the terms accurately define the parameter being measured. The terms used to describe the ends of the scale must also define the magnitude of the scale ends. For example, if one end of a scale is defined by the word "comfortable," all of the subjects may agree as to what is meant by comfort, but may disagree as to what degree of comfort they would report as "comfortable."

The problems of validity arise from the semantic content of the scale descriptors. Subjects may differ as to what meaning they infer from the terms used to define the scale. Also, some subjects may not be familiar with the words being used. To maximize validity of the data collected, terms used to define the scale must be known to all of the subjects, and there must be a high degree of consensus as to the meaning of the terms. Complex definitions based on analogies could be used to better define the magnitudes of the scale ends, but only at the risk of having an increased number of subjects who do not understand the descriptors at all.

5.1.2 SCALE HOMOGENEITY

All too common in ride quality research has been the use of a single scale to simultaneously estimate discrimination, comfort, and tolerance to vibration. Although there may be many parameters of ride perception, such as roughness, pleasantness, comfort, jerkiness, etc., a unidirectional scale must be limited to the estimation of a single parameter.

5.1.3 MATHEMATICAL STRUCTURE OF SCALES

The purpose of using psychometric scales is to obtain information regarding an attitude or an evaluation. Scales must provide data in a form that is suitable for analysis so that information obtained from different subjects can be compared and aggregated in such a way as to support statistically significant conclusions. Semantic content is only one of several considerations in scale development. Of equal importance is the question of mathematical structure of the scales; that is, whether the scale magnitudes imply ordinal, interval, or ratio relationships, and whether the scales are uniquely related to underlying fundamental sensations, perceptions, attitudes, or evaluative parameters. The structure of the scale will then determine both the permissible statistics and the form of the conclusions which may be drawn from the statistics. The various mathematical structures which a scale for the measurement of ride quality may take are as follows:

Ordinal: The relationship between the scale and ride quality is monotonic, implying transitivity of rank order classification of rides; i.e., if Ride A is better than B, and B is better than C, then A is better than C. However, no conclusions can be drawn concerning the relative differences, since an ordinal scale does not imply the existence of a linear relationship between the scale intervals and the parameter being measured. For instance, a change in ride quality from 3 to 4 is not necessarily equal in magnitude to a change from 4 to 5. Allowable statistics are median, percentiles, order correlation, and nonparametric tests.

Scales designed specifically to investigate attitudes, such as Thurston's differential scale and Likert's summated scale, provide only ordinal measurements of the property being investigated. The results obtained from the use of ordinal scales cannot be used to make quantitative judgments of ride to support engineering and system analysis decisions.

Interval: In addition to the properties of the ordinal scale, the units designated by scale numbers in an interval scale are equally spaced; i.e., a change from 4 to 5 is equal in magnitude to a change from 3 to 4. Allowable statistics are mean, standard deviation, product moment correlations, t test, and F test.

Ratio: This scale is similar to an interval scale, with the additional restriction that a scale value of zero refers to an absolute zero of the parameter, so that a change in ride quality from 2 to 4 infers that the quality has doubled.

An important aspect in the development of any scale is the determination of the form of the relationship between the scale responses and the magnitude (and characteristics) of the stimulus. Ideally, this investigation should be performed under closely controlled conditions before the scale is used in a complex real-world setting. The remainder of this chapter describes such a simulator-based investigation of psychometric evaluative scales.

5.2 APPLICATIONS OF PSYCHOMETRIC SCALES TO THE INVESTIGATION OF RIDE QUALITY

Many scaling techniques have been proposed which are designed to assure certain mathematical structures of the responses. The procedural limitations of the captive passenger setting and the fare-paying passenger setting restrict the choice of types of scales to those that do not require comparisons of pairs of ride segments, and to those that are relatively fast and simple to administer. For example, Thurston's Comparative Judgment Technique would require pair comparisons of all ride segments.

A direct approach to obtaining interval scale estimates of a number of undefined factors is the Osgood Semantic Differential Method. This method requires that each subject rate the stimulus on a number of seven-point scales where the end points of each scale are defined by pairs of adjectives having opposite meanings such as strong-weak, warm-cold, rough-smooth, etc. Each adjective pair provides a scale for the estimation of a single property of the stimulus. It is then assumed that the subject's evaluations are actually limited to a smaller number of parameters and that each scale reports the results of a differently weighted combination of these parameters.

If a rating scale defined by a pair of words is actually congruent with a single underlying factor, the Osgood Differential Scale reduces to a single absolute judgment along that scale. The technique of measuring ride quality with a single scale has been widely used in previous ride quality research, and is probably the most practical method for the operational vehicle setting. Recent work by Oborne and Clarke [58a,58b], has demonstrated that practical value of this method for obtaining estimates of defined parameters on an (assumed) interval scale. The two questions which were not addressed in these papers are (1) whether the scale units are of equal magnitude (proof of interval scaling) and (2) whether the scale measures a fundamental property or an attitude.

An important question in the study of ride quality of relative ride comfort is whether "discomfort" is a basic parameter, or whether it is derived by passengers from some weighted function of evaluations of such basic factors as bumpiness, roughness, fatigue-creating potential, and annoyance level of the vibration. We previously discussed the problem of integrating estimates of many physical parameters of the ride to predict comfort. The problem here is the parallel question of identifying and integrating the many psychological factors to predict comfort. The problem has practical implications for the development of predictor equations. If each basic psychological factor is related to a different subset of the physical factors of the ride, it may be easier to develop the functional relationship first between each of a number of basic psychological factors and the ride, and then between these basic factors and comfort. The determination of the important factors influencing ride quality may be possible through the use of the Osgood Semantic Differential Technique, using scale descriptors that relate to vibration characteristics.

The application of the single semantic scale to the measurement of discomfort resulting from vibration has been reported by Dempsey and Leatherwood [19]. A nine-point scale was used, the end points being "zero discomfort" and "maximum discomfort." The responses are assumed to be interval scaled, and for practical purposes, this is an acceptable assumption since the definition of "comfort" presented in previous chapters did not define the meaning of "units of discomfort" except in terms of zones of indifference.

5.3 EXPERIMENTAL TESTING OF PSYCHOMETRIC SCALES

Many basic questions confront the experimenter who wishes to use psychometric scales in the investigation of the ride quality of operational vehicles. Care must be taken to assure that the scales are valid and that the defining terms do not result in semantic problems caused by differing passenger interpretations. While all of these technical points must be considered, there is one central requirement for any scale used in ride quality research; namely, that subject responses to vibration must be consistent, i.e., reliable. If the same subjects responding to the same ride on successive runs cannot agree as to the roughness of the ride as evaluated by comfort or some such appropriate measure, the results of the experiment would be of limited value. If results of one test run cannot predict results of the next, it is not reasonable to expect that they could predict anything else. From review of the literature, it is not certain that high test-retest reliability can be obtained.

The experimental validation of the psychometric scales requires that they be used to obtain evaluations of realistic, complex, vibration environments which can be accurately repeated. These requirements suggest that the simulator setting will provide the most suitable basis for the development and validation of the psychometric scales required for the experiments to be conducted on operational vehicles.

The experiments described in the following sections represent a first attempt to explore several of the issues related to the use of psychometric scales of the Osgood Differential type.

Three problem areas and associated issues were examined:

> The extent to which subject response to vibration can be accounted for by type and amplitude of vibration, and the extent to which variations in response can be attributed to inter- and intra-individual differences.
>
> The extent to which subjects are able to differentiate the comfort of different rides

within the envelope of rides expected on vehicles of a single transportation mode.

The extent to which subjects can differentiate between rides and the ways in which the reported evaluations of ride components are related to evaluations of ride comfort.

5.4 EXPERIMENT I: DEVELOPMENT OF PSYCHOMETRIC SCALES--RELIABILITY AND CONSISTENCY

Experiment I, which is described in this section, was conducted to determine whether subjects can reliably and consistently distinguish between different rides experienced on interurban trains. The objectives which follow deal with subjective discrimination and evaluation of four types of rides. These ride segments were recorded by the FRA Portable Ride Quality Apparatus during an actual passenger train ride and were reproduced in the simulator. The physical characteristics of the ride segments are described in detail in Appendix E.

OBJECTIVE 1. RIDE QUALITY EVALUATION

Subjective evaluations of ride quality were obtained for four rides that are characteristic of passenger trains operating on different types of track. The rides are designated by the following names: smooth ride; continuous rough ride; lateral event ride; and roll coupled vibration ride. All the rides except the smooth ride were presented at low, medium, and high levels of amplification of the acceleration levels. The amplitude of the smooth ride was held constant as a reference.

OBJECTIVE 2. EVALUATE DESCRIPTIVE SCALES OF RIDE QUALITY (COMFORT)

The rating scale utilized to obtain an overall evaluation of comfort was a unipolar scale developed by Dempsey [19]. Bipolar scales were used to have subjects respond to more specific aspects of vibration in order to evaluate the relevance of scales and their relationship to predetermined variations in vibration.

Evaluation of ride is really a two-staged process: the subject feels the vibration; then reports his reaction to the vibration. Different subjects may not "feel" the same vibration due to difference in somatotype and other factors. Even if the subjects feel the same vibration, they may not necessarily choose the same terms to describe their feelings. The use of predefined semantic scales reduces the variation in responses due to language differences among the subjects, but it should not be assumed that all of the subjects interpret the meanings of the scales in the same way. The experiment was therefore designed to determine whether there were reliable differences in the way different rides were described by use of a group of different descriptive bipolar scales.

OBJECTIVE 3. SCALE RELATIONSHIPS TO STIMULUS

The relationship between scales developed in Experiment I and stimuli consisting of variations in vibration characteristic of passenger train ride was explored. Scales having the best correlation with each other, with the scale group as a whole and with the Dempsey/Leatherwood nine-point scale of discomfort were extracted using multiple regression analysis from all scales used to measure subjects' responses to a series of vibration stimuli.

OBJECTIVE 4. MEASURES OF INTER- AND INTRA-SUBJECT VARIANCE

Typically, studies in simulators and studies of passengers in operational vehicles have not replicated stimulus conditions using the same subjects. When developing means by which passengers may evaluate ride quality, it is quite important to know to what extent variance obtained is attributable to inter-subject differences; and what fraction of the variance obtained is intra-subject. These data were collected to conform to a repeated-measures design.

Ratings of three habitability components (seat, temperature and air quality) were used as indicators of inter-subject differences, and as a check on the comfort/discomfort level of the subjects. Some people may give consistently low discomfort ratings; others may have a bias for the high end of the scale due to the effects of habitability factors. The habitability ratings were used to identify the causes of constant tendencies in either direction among subjects, thus permitting control of, or adjustment for, consistent differences between subjects in rating tendencies.

5.4.1 DESIGN OF EXPERIMENT

The NASA Langley Simulator

The NASA Langley Passenger Ride Quality Apparatus was utilized. The apparatus simulates vertical, lateral, and roll motions with accelerations limited to 0.5 g. Stimulus values, stimulus duration, and presentation schedules were recorded on analog magnetic tape for presentation to subjects. Instructions were given prior to each run and orally during each run as had been done during previous experiments using this apparatus [15,72]. Input stimuli transmitted to subjects were measured by accelerometers built into one of the seat cushions, and were displayed during the test on a pen chart. Seats used were those from the available NASA Langley seat pool which most closely resembled Metroliner seats. General methodology followed that suggested by Dempsey and Leatherwood [19].

Subject Population

The sample population was obtained locally for the experiment by Bionetics, Inc., and Old Dominion University. The 18 subjects used in Experiment I were, for the most part, students and under the age of 30.

Experimental Design

A 12-cell design was used in Experiment I to present four different ride segments at predetermined vibrational amplitudes to the subjects in a randomized order. The purpose of this experiment was to obtain preliminary information on both the characteristics of the simulator and on the usefulness of various scales within this setting. The 12-cell design therefore was addressed to a number of different purposes, and was not intended to be an efficient test of a single hypothesis.

Four different segments of ride were used to define the stimulus conditions. These segments were recorded onboard a railroad passenger car and selected as representative of the following four different types of rides:

R1 = lateral event--the response of a car passing over three switches and changing tracks.

R2 = continuous rough--the response of the car on rough track.

R3 = roll--the response of the car as it passed over a series of switches and misaligned track known to induce a rolling motion of the car.

S = smooth--the response of the car on smooth high-speed track.

The characteristics of these four ride segments are described in detail in Appendix E.

The amplitude of these recorded vibrations presented to the subjects could be changed from that recorded on the railroad car by changing the amplifier gains on the simulator. The rides R1 and R2 were presented at three levels: the amplitudes of vertical, lateral, and roll vibrations were adjusted simultaneously to present a ride of 1/2, 1 or 2 times the acceleration levels measured on the car. The ride R3 had only the roll amplitudes adjusted to 1/2, 1 or 2 times the recorded level while maintaining the amplitude of vertical and lateral vibrations at the normal levels; this was done to determine whether the roll motions were significantly related to the subjects' perceptions of the ride. The smooth ride was presented three times at normal amplitude to determine the repeatability of the ratings assigned to a specific level of ride. The entire sequence of 12 rides was presented twice, with a rest period between presentations, to determine the stability of the responses obtained on the scales. Because of the different characteristics of the four ride segments, four different sets of bipolar scales were used so as to determine which pairs were particularly descriptive of each ride.

5.4.2 CONDUCT OF EXPERIMENTS

Design

Each run consisted of one exposure period for each of the 12 ride segments. Exposure time was about two minutes per segment, and each exposure followed by a pause of approximately 1-1/2 to 2 minutes. The ride segments were presented to subjects at low, medium, and high amplification. One smooth ride segment was presented as a stimulus three times during each experimental run.

The relative amplitudes of the various rides were varied as follows:

	Ride								
	R1			R2			R3		
Level	Vert	Lat	Roll	Vert	Lat	Roll	Vert	Lat	Roll
L	1/2	1/2	1/2	1/2	1/2	1/2	1	1	1/2
M	1	1	1	1	1	1	1	1	1
H	2	2	2	2	2	2	1	1	2

The order of the presentation of the ride segments during test runs 1 and 2 was as follows:

	Run 1/each group	Run 2/each group
1.	Smooth	R_1M
2.	R_3H	Smooth
3.	R_1M	R_2M
4.	Smooth	R_3L

(continued)

	Run 1/each group	Run 2/each group
5.	R_3L	R_1H
6.	R_1L	R_2H
7.	Smooth	R_3M
8.	R_2L	Smooth
9.	R_2H	Smooth
10.	R_2M	R_1L
11.	R_3M	R_3H
12.	R_1H	R_2L

Run 2 is a replication of the ride segments presented in Run 1; however, in order to minimize the possibility of a spuriously high reliability due to subjects remembering roughness of prior ride segments, the ride segments were again randomly ordered. During the pause between exposures, subjects were instructed to rate the exposure they had just experienced. Formats for collection of data are shown in Appendix VI.

Habitability Ratings

After each run, subjects rated three habitability parameters on seven-point scales: seat comfort, temperature, and air quality. See Appendix VI.

5.4.3 ANALYSIS OF RESPONSES TO UNIPOLAR SCALE FOR PERCEIVED COMFORT

A nine-point unipolar scale previously developed by Dempsey [19] was used to obtain direct measurements of the perceived comfort of each ride segment. The ends of this scale were defined by the phrases "zero discomfort" and "maximum discomfort."

Subject evaluations of the 12 ride segments are tabulated in Table 5-1. This data was analyzed using a number of parametric statistical techniques as described in the following paragraphs. However, no test was made of the implicit assumption of interval scaled data. Such a test was performed on the

Table 5-1. Ride-Ride Quality Relationships
Summary From Data Sheets; Reliability Computations

Note: Twelve subjects in groups of six (Group A and Group B) were subjected to 12 vibration stimuli in the NASA Langley Simulator. Three vibration stimuli represented identical smooth rides. Nine represented three different types of rough rides; each rough ride was presented at three amplitudes. The experiment was replicated (Runs 1 and 2) to provide reliability data. Subject ratings for each stimulus are presented below.*

		STIMULI																										
		S_1**		R_3H		R_1M		S_2		R_3L		R_1L		S_3		R_2L		R_2H		R_2M		R_1H		R_3M		Totals		
		Run		Run		Run		Run		Run		Run		Run		Run		Run		Run		Run		Run		Run		r^2 for subjs.	
Subj	Sex	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2		
1	F	2	2	4	7	3	3	4	2	4	6	1	1	2	2	0	0	5	3	3	2	7	7	5	4	40	39	.936	GROUP A
2	F	2	2	4	6	5	1	2	1	4	5	1	1	1	0	0	0	7	7	1	0	7	8	3	5	37	36	.927	
3	F	1	2	5	4	2	2	2	1	4	4	0	2	0	1	0	0	7	4	1	1	7	7	2	3	31	31	.940	
4	F	3	3	5	7	4	5	6	3	8	4	1	2	3	0	3	0	6	7	5	3	9	8	4	6	57	48	.904	
5	M	7	3	8	7	7	3	4	4	8	5	2	3	3	4	2	0	7	5	6	2	8	8	4	6	66	50	.921	
6	F	4	1	7	7	6	3	2	4	7	6	0	1	2	2	2	0	3	7	2	2	6	8	3	6	44	47	.888	
7	F	3	4	7	9	2	5	4	4	6	8	2	5	4	4	3	2	5	8	5	4	7	9	5	7	53	69	.971	GROUP B
8	M	9	7	9	9	8	8	8	8	9	9	6	7	7	7	7	7	8	8	7	7	9	9	9	9	96	95	.997	
9	M	4	5	6	8	6	6	4	6	6	7	1	2	4	5	2	2	6	8	6	3	7	8	6	8	58	68	.974	
10	M	7	5	8	8	7	6	7	7	8	7	4	6	8	7	6	5	8	8	6	4	8	8	8	8	85	79	.988	
11	M	3	5	6	6	6	6	5	6	7	6	3	3	4	5	2	3	5	6	4	4	7	7	6	6	58	62	.985	
12	F	6	6	3	8	6	6	5	4	9	7	4	3	7	5	1	4	7	8	7	7	9	9	7	8	76	75	.980	
Means by Stimulus		4.3	3.8	6.4	7.2	5.2	4.4	4.4	4.2	6.7	6.2	2.1	3.0	3.8	3.5	2.3	1.9	6.2	6.6	4.4	3.3	7.6	8.0	5.2	6.3	r total scores = .992			
r^s for stimuli		.916		.973		.92		.934		.959		.875		.875		.873		.952		.951		.994		.974					

* Rating Scale
** Identification of Stimuli:

$S_1S_2S_3$ = smooth runs, all identical
R_1 = lateral event
R_2 = continuous rough ride
R_3 = roll event
L,M,H = low, medium, high amplitude respectively

A nine-point scale was used:

Zero Discomfort 0-+-+-+-+-+-+-+-+-0 Maximum Discomfort

Table 5-1. Ride-Ride Quality Relationships (continued)

Summary from Data Sheets

NOTE: This table is a continuation of Table 5-1. It presents by subjects 13-18, i.e., Group C, for the same stimuli shown in Table 5-1.

SUBJ	SEX	STIMULI											
		S_1	R_3H	R_1M	S_2	R_3L	R_1L	S_3	R_2L	R_2H	R_2M	R_1H	R_3M
		1	2	3	4	5	6	7	8	9	10	11	12
13	M	5	5	5	6	6	5	5	5	7	5	8	8
14	M	3	7	7	5	6	7	5	3	7	5	8	8
15	M	1	5	7	7	5	0	3	4	6	6	9	7
16	M	2	6	7	7	7	5	7	3	7	6	8	8
17	F	6	8	7	6	7		6	3	8	7	9	8
18	M	3	6	5	5	5	5	6	2	6	5	7	7

data obtained in Experiment II; the results (page 5-36) support the assumption that the psychometric scales provide interval scaling of the logarithm of the amplitude of the vibrations.

5.4.3.1 Analysis of Variance--12 Subjects, Repeated Runs

The test-retest correlation coefficients for the twelve subjects are listed in Table 5-1. The lack of significant differences in subject response between the runs indicates high intra-subject reliability ($r = 0.939$). The individual subject test-retest ratings of from 0.88 to 0.99 are a further indication that the subjects tended to assign approximately the same comfort ratings to each ride segment in both presentations. This result also suggests that there is little effect due to the order in which the ride segments are presented and carry-over effects from one segment to the next.

The comfort scale responses were analyzed using a three-way repeated measures design. The smooth ride responses were omitted, as the amplitude was not varied for this ride. The factors analyzed were:

S	Subjects (12)
Ri	Rides (3)
A	Amplitudes (3)

The results of the calculations of the mean square errors and significance levels are shown in Table 5-2. The following conclusions may be inferred from these calculations.

Subjects: The way in which the subjects differed from each other was found to be significantly related to the specific ride segment.

Table 5-2. Repeated Measures Analysis of Variance of Responses by 12 Subjects on 9-Point Comfort Scale

	Sum of Squares	df	Mean Squares	F	P
Between Subjects					
Subjects	423.98	11	38.544	17.64	.01
Error	26.22	12	2.185		
Within Subjects					
Ride	404.51	2	202.25	183.53	.01
Subject x Ride	58.82	22	2.674	2.43	.05
Error	26.44	24	1.102		
Amplitude	177.01	2	88.50	69.14	.01
Subject x Amplitude	17.32	22	0.787	.615	
Error	30.78	24	1.28		
Ride x Amplitude	161.38	4	40.345	10.73	.01
Subject x Ride x Amplitude	46.62	44	0.463	.123	
Error	180.57	48	3.76		
TOTAL	1553.64	215			

Amplitudes and Ride Segments: The analysis of variance demonstrates significant effects of both amplitude and the specific ride segment on the comfort ratings. This difference is analyzed in detail in Section 5.4.3.3.

Ride x Amplitude Interactions: There are significant differences among the rides in the way subjects respond to the changes in amplitudes. The "lateral event" and the "continuous rough" segments essentially vary together as amplitude increases. Comfort ratings of the "roll" segment, where only the amplitude of the roll motion was varied, differ little with changes in amplitude and that only at the highest amplitude level. Three reasons for this effect may be hypothesized:

1. The simulator is limited in its independent response to changes in roll motion. This is considered unlikely based on a review of the simulator performance specifications.

2. Subjects are not able to discriminate changes in roll amplitude. This would have to be checked by using roll motion alone vs. a stimulus.

3. There is a significant masking effect between the various axes of motion. Given a fixed level of vertical and lateral motion amplitudes, roll will only affect the overall comfort evaluation if the amplitude of the roll motion exceeds some definite threshold.

Other Interactions: No other significant interactions were noted.

5.4.3.2 Analysis of Variance--18 Subjects, All Runs

Because there were no significant differences between runs, the data from repeated runs was collapsed by averaging the responses of each subject to each ride segment, and by averaging all of the responses by each subject to the smooth ride. A repeated measure analysis of variance of the comfort evaluations of the medium amplitude rides was then performed for the following factors:

Gender (2)
Ride (4)

The results of the calculations are shown in Table 5-3. The following conclusions may be inferred from these calculations.

Gender: Males rate the rides as significantly more discomforting than do females. For instance, for the smooth ride:

	Mean Rating	V (Mean)
Males	5.29	.0707
Females	3.02	.0745

Table 5-3. Analysis of Variance of Ratings of Normal Amplitude Rides

Responses on 9-point comfort scale, 18 subjects, responses averaged between runs 1 and 2:

Factor	df	Sum of Squares	Mean Squares	F	P
Gender	1	65.35	65.35	28.92	0.001
Ride	3	49.75	16.58	7.34	0.001
Gender x Ride	3	0.65	0.22	.10	
Residual	64	144.54	2.26		
Total	71	260.29			

Ride: The relationships between ride segment, amplitude, and comfort rating are shown in Figure 5-1. The comfort ratings of the normal amplitude rides as obtained from the total number of responses obtained from the 12 subjects where the ride was replicated are as follows:

Ride	N	Avg. Comfort $\overline{C}$	$\sigma(\pm$ 1.s.d.)
R_1	24	4.80	2.0
R_2	24	3.83	2.2
R_3	24	5.75	1.9
S	72	3.97	2.2

Testing for the significance of the differences in these mean comfort ratings, we obtained:

$$Z = \frac{\overline{C}_i - \overline{C}_j}{\sqrt{\frac{\sigma_i^2}{N_i} + \frac{\sigma_j^2}{N_j}}} \quad , \ P(Z>0)$$

Pair	Z	P(Z>0)
R_1-R_2	1.59	.944
R_1-R_3	1.67	.953
R_1-S	1.71	.956
R_2-R_3	3.20	>.999
R_2-S	.27	<.5
R_3-S	3.76	>.999

5.4.3.3 Other Causes of Variability in Comfort Ratings

Intersubject Differences: In spite of the high intrasubject reliability, it is evident from inspection of differences in total scores (see Table 5-1 on page 5-15, right-hand column) that subjects are using different ranges within the scale in

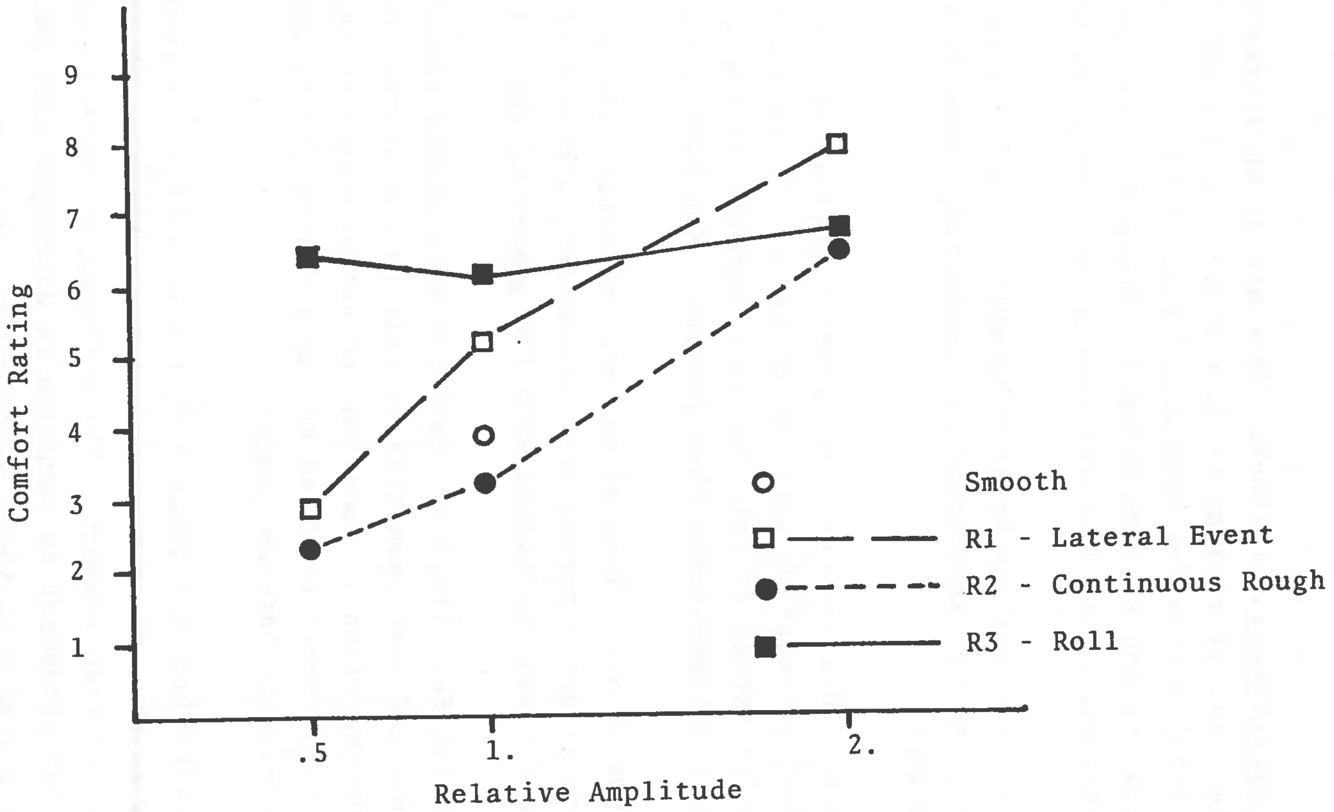


Figure 5-1. Relationship of Type of Ride and Relative Amplitude of Accommodations to Average Comfort Ratings--Experiment I

making ratings. These between-subject differences can be noted from inspection of total scores in Table 5-1.

Group Differences: Further, there are group differences. Fo example, comfort ratings of five members from Group A show lower total scores for both runs--indicating less discomfort-- than did any member from Group B. Group C, also testing in the afternoon, showed scores similar to those from Group B.

These differences may be attributable to one or more of three factors. As the experiment was conducted, these factors were confounded:

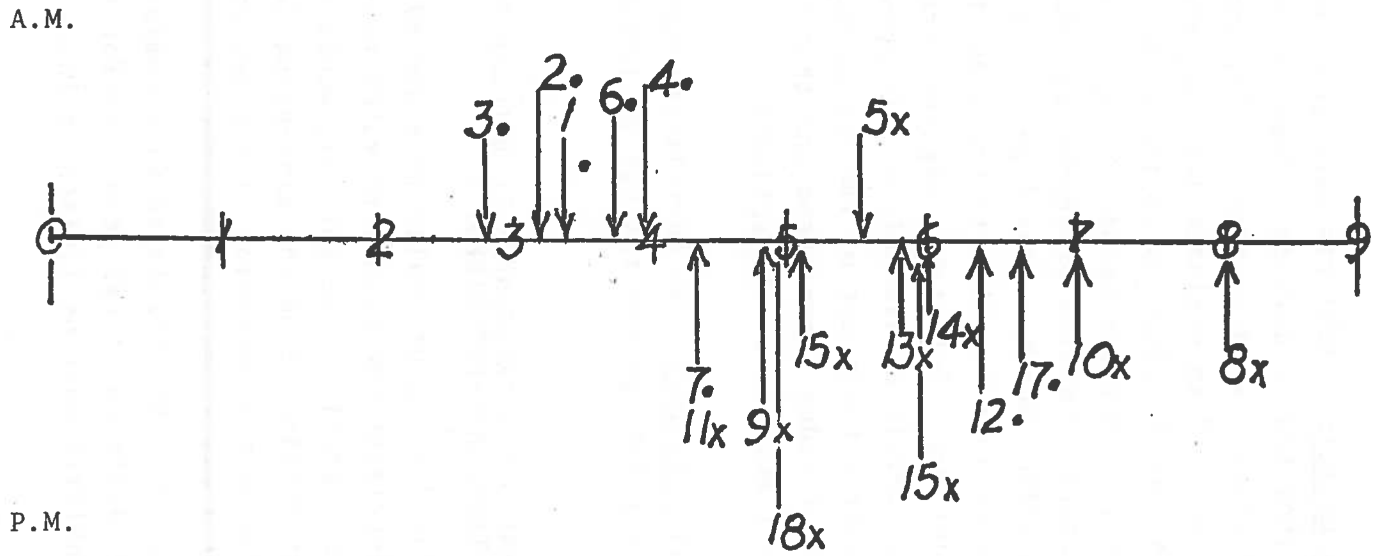
1. Gender differences. The comfort ratings show a significant correlation with the gender of the 18 subjects; males tended to rate the ride segments as significantly more uncomfortable than females. See Figure 5-2.
2. Time of day. Time of day may influence ratings. Morning groups reported less discomfort, although this factor was confounded with the gender of the subjects.
3. Social facilitation. Subjects were seated side-by-side and were permitted to talk to one another during the experiment. Conscious or subconscious social facilitation cannot be ruled out as a reason for differences in ratings between groups.

These individual and group differences indicate a need for caution in the use of mean or average ratings as absolute measures of ride comfort. The differences further indicate a need for attention to sampling to determine what parameters are correlated with these differences. As of now, a sizable sample is needed to accurately estimate population statistics, since the standard deviation of the distribution of comfort ratings is 1.9 units. With small samples of six, it is

Figure 5-2. Mean Values: Discomfort Ratings

(N = 18)

Note: Six subjects were tested in the morning (Group A) and the run was replicated. Six subjects were tested in the afternoon (Group B) and the run was replicated. Six additional subjects were available (Group C). They were tested only once. The numbers designate subjects in the above order starting with morning tests.



No. Given = subject no.
X = Male
● = Female

possible to obtain great differences in evaluations of identical ride segments as a function of sampling fluctuations.

Learning Effects: Subjects were given no "warm-up" prior to Run 1. They had to develop a frame of reference for evaluations as stimuli were presented. The Duncan Multiple Range Test can be used to evaluate learning effect, and concurrently to provide clues as to the number of subjective levels of discomfort that may exist for the stimulus excursions used in this study. Results presented in Table 5-4 suggest some learning effect between Runs 1 and 2, as the subjects appear to be better able to classify the rides by comfort in the second test run. This table suggests the presence of four subjective levels of discomfort. It appears that the subjects adjusted their use of the rating scale on the basis of the range of rides experienced and that the scale ends have no *a priori* meaning to the subjects.

Habitability Ratings: No correlation was found between habitability ratings and ratings of discomfort due to vibration.

5.4.4 ANALYSIS OF RESPONSES TO BIPOLAR SCALES OF RIDE ATTRIBUTES--EXPERIMENT I

The bipolar descriptor scales (see Appendix VI) were evaluated to determine the extent to which these scales, designed to describe specific ride motions, would add to predictions of comfort obtained from the nine-point General Comfort Scale. The purpose of the inclusion of the descriptor scales in Experiment I was to determine which of a number of carefully selected terms best correlated with comfort for each ride. Therefore, different terms were used for the different rides, and the analysis must be limited to individual ride types.

1. All descriptor scales are highly correlated with the comfort scale.

Table 5-4. Multiple Range Test (Duncan) on Nine-Point Comfort Scale

(Significance of differences between means. Values from 1% level of significance table of studentized ranges.)

Rank Ordered Mean Values of Responses to Stimuli

Run 1: Subjects 1-12

R_1L	R_2L	S_3	S_1	R_2M	S_2	R_1M	R_3M	R_2H	R_3H	R_3L	R_1H
2.1	2.3*										
		3.8	4.3	4.4	4.4						
			4.3	4.4	4.4	5.2	5.2				
						5.2	5.2	6.2	6.4		
								6.2	6.4	6.7	
									6.4	6.7	7.6

Run 2: Subjects 1-12

R_2L	R_1L	R_2M	S_3	S_1	S_2	R_1M	R_3L	R_3M	R_2H	R_3H	R_1H
1.9	3.0										
	3.0	3.3	3.5	3.8	4.2	4.4					
							6.2	6.3	6.6	7.3	
										7.2	8.0

*Lines indicate groups of means within which no significant differences exist.

2. Analysis of the data suggests that subjects are relatively insensitive to differences between types of vibration used in the simulator.

These results are illustrated in Table 5-5 for correlations between four bipolar scales and the comfort scale. A correlation computed between Scale 3 of the "lateral event" (smooth-bumpy) and Scale 12 (rhythmic-jarring) was 0.99.

Table 5-5. Some Correlations of Descriptor Scales with the Comfort Scale

	Run 1
	n = 18
Roll ride: Scale 3 (smooth-rolling)	0.96
Smooth ride: Scale 7 (soothing-annoying)	0.94
Continuous rough: Scale 10 (smooth-rough)	0.89
Lateral event: Scale 3 (smooth-bumpy)	0.92

All descriptor terms were not used across all four rides, and the subjects' responses using these scales cannot provide evidence that subjects can discriminate between different types of vibration. We are inclined to believe--at least we would like to believe--that subjects can discriminate between different rides. Several issues thus deserve further inquiry:

1. Insofar as we know, there exists no definitive "map" by which factors or types of vibration are related to nontechnical descriptions of vibrations. Further, subjects may not agree as to their descriptions of vibration. Informal interviews with subjects after the experiment suggest this to be the case.

2. An alternate experimental approach would be to examine the terminology of the scales and to try to make each

scale unipolar. The scales used during Experiment I were carefully chosen to be applicable to the type of ride, and different scales were presented for each of the four ride segments. Problems could occur if these special descriptive scales were used to measure aspects of ride to which they did not apply. The reason for this is that subjects have no obvious way to mark a scale when its terms do not "fit" the vibration in question. If, for example, the predominant motion is rolling, the question arises as to how to mark scales such as:

Smooth - - - - - - - - - - - - - - - - - - Bumpy
Rhythmic - - - - - - - - - - - - - - - - - Jarring

Using a forced-choice method as we did, where should the subjects place their marks on the scales above?

A two-step approach might have subjects discriminate first whether the scale's adjectives are applicable. Next, the subjects could only use those scales that are judged properly descriptive of vibration for evaluations. Alternatively, subjects could be instructed to mark in applicable scales in the middle, indicating no preference for either descriptive term. Subjects were so instructed during Experiment II.

5.4.5 SUMMARY OF RESULTS--EXPERIMENT I

The most promising finding was the high reliability of each subject's evaluation of ride comfort levels. From the literature, one could not be sure that this result would be obtained.

Caution should be exercised in using the general ride quality scale as an absolute measure of discomfort. Although the ratings by each subject are reliable, as shown by low intrasubject differences, different subjects tend to use different portions of the scales.

A number of issues deserves further inquiry.

> Subjects discriminated well between stimulus amplitude for the lateral event segment and continuous rough rides; not, however, for roll. This may be an indication of stimulus masking on the roll axis.
>
> Significant differences were found between comfort ratings between morning and afternoon groups. These could be attributed to either gender or time of day, since these factors were confounded in the experiment.
>
> The ability of subjects to discriminate between different types of vibration using descriptive scales has not been demonstrated. However, the experiment was not designed to investigate this question.

5.5 EXPERIMENT II: TESTING OF PSYCHOMETRIC SCALES FOR COMFORT AND VIBRATION FACTORS

Experiment II represented a further exploration of the factors and relationships developed in Experiment I. Emphasis was placed on the following:

OBJECTIVE 1. RELIABILITY OF RATINGS

As the magnitude of vibration is reduced, is there a subsequent reduction in intrasubject reliabilities of ratings of vibration?

OBJECTIVE 2. SEX DIFFERENCES/TIME OF DAY

Will differences in ride comfort ratings as a function of sex and/or time of day discovered in Experiment I remain?

OBJECTIVE 3. SCALE DEVELOPMENT

Further exploration of various descriptors used in bipolar scales. Can descriptors be found which will better correlate with types of vibration?

5.5.1 DESIGN OF EXPERIMENT

The NASA Langley Simulator. The same apparatus and physical procedure was used for Experiment II as for Experiment I.

> Subject Population: Twenty-four subjects were obtained through Bionetics, Inc. The four groups of six subjects each had three males and three females, and there was a wide distribution of age (21 to 65 years) and economic background. Age and demographic information was obtained from each subject.
>
> Experimental Design: The same simulator control tape was used in Experiment II as in Run 1 of Experiment I. The amplitude of the vibrations was varied for all four runs, and by an equal amount on all three axes of motion. The medium amplitude level (1.0) used in Run 1 of Experiment II was the same as the medium level used in Experiment I. Run 2 of Experiment II was a repeat of Run 1, except all amplitudes were reduced by 40 percent, an amount which covered the full range of amplitude variability within the linear response range of the simulator.

5.5.2 CONDUCT OF EXPERIMENTS

Design

Each run consisted of one exposure period for each of the 12 ride segments. The order of presentation and amplitude of the ride segments is shown in Table 5-6 for the two test runs. During the 90-second pause between ride segments, subjects were instructed to rate the ride they had just experienced using 15 bipolar descriptive scales, one unipolar comfort scale (i.e., the Dempsey Scale) and one unipolar acceptability scale. Formats for the collection of data are shown in Appendix F.

Habitability Ratings

At the end of each test run, the subjects were instructed to rate the habitability factors of seat comfort, temperature, and air quality. Bipolar scales were provided for each of these factors.

Table 5-6. Experiment II Ride Segment Presentation Schedule

Order of Presentation	Ride Segment	Run 1 Amplification	Run 2 Amplification
1	Smooth	2.0	1.2
2	Roll	2.0	1.2
3	Lateral event	1.0	0.6
4	Smooth	0.5	0.3
5	Roll	0.5	0.3
6	Lateral event	0.5	0.3
7	Smooth	1.0	0.6
8	Continuous rough	0.5	0.3
9	Continuous rough	2.0	1.2
10	Continuous rough	1.0	0.6
11	Lateral event	2.0	1.2
12	Roll	1.0	0.6

Demographic Factors

There was a 20-minute break between the runs. During this break, the subjects completed the demographic information portion of the questionnaire.

5.5.3 ANALYSIS OF RESPONSES TO UNIPOLAR SCALE FOR PERCEIVED COMFORT

5.5.3.1 Mean Ratings of Discomfort

The means for levels of discomfort were lower for Run 2 than for Run 1. The mean for all subjects for Run 1 is 4.354 ($\sigma = 2.13$); for Run 2, 3.097 ($\sigma = 2.38$). This indicates again consistent ability of subjects to discriminate between stimulus levels and a consistent tendency to evaluate lower amplification vibrations as more comfortable; i.e., as being associated with less discomfort.

5.5.3.2 Reliabilities

An analysis of variance was performed for the data from each test run. The results of the calculations are summarized in Tables 5-7 and 5-8.

We also note that reliabilities for Run 2 are slightly higher than for Run 1. This result indicated that subjects are still able to discriminate well between stimulus excursions as stimulus amplifications are reduced from a range of .5, 1.0, 2.0 of actual signatures to a range of .3, .6, and 1.2 of reduced stimulus signatures. The slightly high reliabilities for Run 2 may be attributed to frequent use of the zero discomfort end of the scale for stimulus amplification of .3. Also, to the fact that having been subjected to all stimuli on Run 1, subjects had a better frame of reference for evaluation of stimuli presented subsequently.

5.5.3.3 Gender/Time of Day

A four-way repeated measures analysis of variance was performed on the responses to the comfort scale in order to identify possible effects of the gender of the subjects and the time of day of the test runs. The results of the calculations* are shown in Table 5-9. The ride comfort ratings were not found to be significantly correlated with either the gender of the subject nor the time of day, nor were there any significant interactions between these factors and either the rides on the relative amplitudes of the rides.

---

*Following the example given in: Winer, B. S., Statistical Principles in Experimental Design, New York: McGraw-Hill 1971, p. 574.

Table 5-7. Analysis of Variance, Run 1 Comfort Ratings

Subject Response on Comfort Scale by
Amplification Levels of 0.5, 1.0 and 2.0 Ride

FACTOR	N	df	SUMS OF SQUARES	MEAN SQUARES	F	P
Amplification Level	3	2	366.87	183.34	33.82	0.01
Ride	4	3	99.87	33.29	6.14	0.01
Subject	24	23	552.16	24.01	4.43	0.01
Residual	257	259	1404.58	5.42	---	---
Total	288	287	2423.48			

$r_{subjects} = 0.77$

$r_{level/amplification} = 0.97$

$r_{ride} = 0.84$

Subjects: 12 Male and 12 Female; ages 21-65

Ride types: Lateral event; continuous rough; roll; smooth

Table 5-8. Analysis of Variance, Run 2 Comfort Ratings

Subject Response on Comfort Scale by
Amplification Levels of .3, .6, and 1.2 and Ride

VARIANCE	N	df	SUMS OF SQUARES	MEAN SQUARES	F	P
Amplification Level	3	2	669.30	334.65	92.96	0.01
Ride	4	3	105.54	35.18	9.77	0.01
Subject	24	23	452.25	19.66	5.46	0.01
Residual	257	259	931.94	3.60		
Total	288	287	2159.03			

$r_{subjects} = 0.82$

$r_{level/amplitude} = 0.99$

$r_{ride} = 0.90$

Subjects: 12 Male and 12 Female; ages 21-65

Ride types: Lateral event; continuous rough; roll; smooth

Table 5-9. Four-Way Repeated Measure Analysis of Variance of Comfort Responses

SOURCE	SUM OF SQUARES	df	MEAN SQUARES	F	P
Between Subjects					
Gender	81.000	1	81.000	2.198	>.1
Time	.444	1	.444	.012	>.1
Gender x time	79.507	1	79.507	2.158	>.1
Error	736.82	20	36.841		
Within Subjects					
Ride	197.563	3	65.854	26.934	<.0
Gender x ride	14.514	3	4.838	1.979	>.1
Time x ride	5.042	3	1.681	.687	>.1
Gender x time x ride	3.813	3	1.271	.520	>.1
Error	146.691	60	2.445		
Amplitude	1229.208	5	245.842	21.595	<.0
Gender x amplitude	29.646	5	5.929	.521	>.1
Time x amplitude	5.451	5	1.090	.096	>.1
Gender x time x amplitude	5.681	5	1.136	.100	>.1
Error	1138.438	100	11.384		
Ride x amplitude	118.75	15	7.917	.105	>.1
Gender x ride x amplitude	45.257	15	3.017	.040	>.1
Time x ride x ampl.	14.813	15	0.988	.013	>.1
Gender x time x ride x amplitude	27.614	15	1.841	.024	>.1
Error	22722.023	300	75.740		
TOTAL	26602.272	575			

5.5.3.4 Ride

The mean responses to each ride at each amplitude are shown in Figures 5-3a and 5-3b. The increased linearity of the relationship when the comfort ratings are plotted as a function of the logarithm of the amplitude suggests that Steven's Power Law holds for this relationship as for most other psychophysical phenomena. The least squares regression equations that best fit this data are as follows:

Smooth Comfort Rating = 3.51 + 4.89 log amplitude
SY.X = 0.955
$r^2 = .66$

Lateral Event Comfort Rating = 4.76 + 5.33 log amplitude
SY.X = 0.777
$r^2 = .77$

Continuous Rough Comfort Rating = 3.70 + 5.75 log amplitude
SY.X = 0.207
$r^2 = .98$

Roll Coupled Vibration Comfort Rating = 4.89 + 5.21 log amplitude
SY.X = 0.551
$r^2 = .86$

Based on the best estimates of the comfort ratings at normal (1X) amplitudes, we can conclude that:

> The smooth and continuous rough rides are not significantly different in comfort: t (smooth - rough) = 0.43, d.f. = 10
>
> The lateral event and roll rides are not significantly different: t (lateral - roll) = -0.31, d.f. = 10

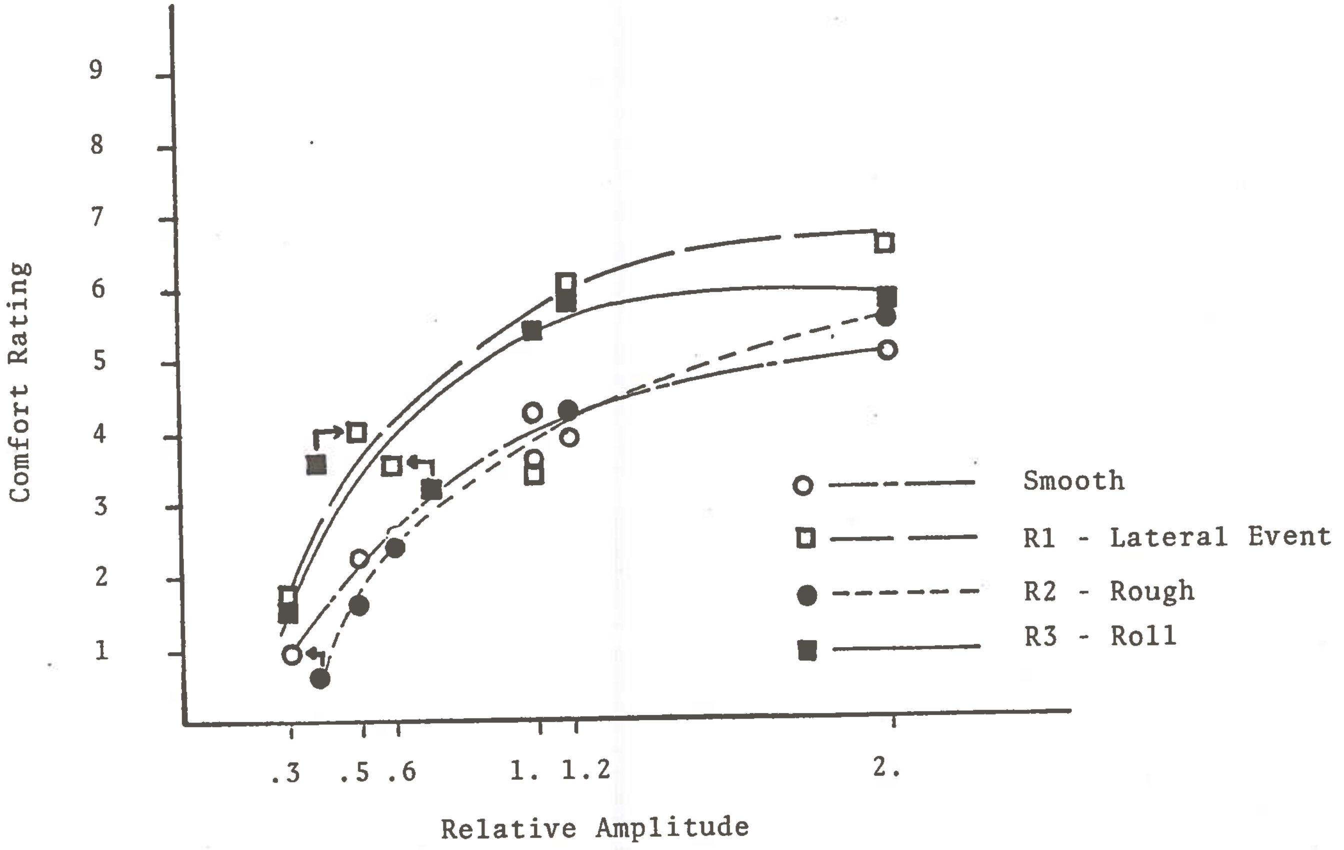


Figure 5-3a. Relationship of Type of Ride and Relative Amplitude of Acceleration to Average Comfort Ratings - Experiment II

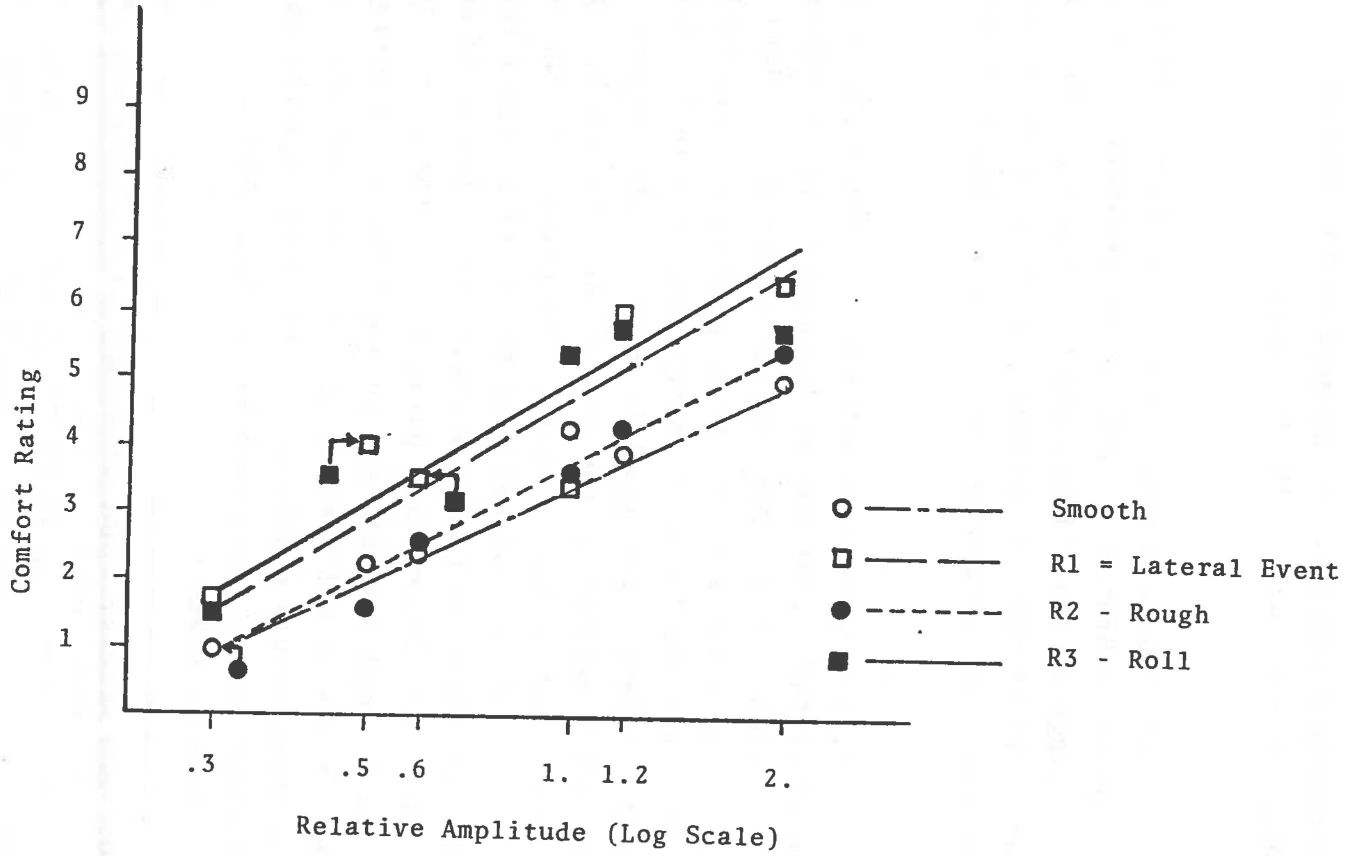


Figure 5-3b. Relationship of Type of Ride and Relative Amplitude of Acceleration to Average Comfort Ratings - Experiment II (continued)

> The continuous rough and lateral event rides are significantly different: t (lateral event -continuous rough) = 2.95, d.f. = 10, $P < 0.01$

The four rides differed significantly in terms of the frequency distribution of the vibrational energy, the probability of the occurrence of large accelerations, and the occurrence of vibrational events. These physical parameters of the rides at the normal (1.0) amplitude levels are described in detail in Appendix V.

More importantly, the rides also differed significantly in the average energy of the vibrations as measured by rms acceleration levels in each of the three degrees of freedom. These rms levels are listed in Table 5-10. By inspection of this table, it can be seen that the greatest energy input was in the vertical direction. Rank ordering of the rides by the vertical vibrational energy results in the same order obtained by ranking by the perceived comfort ratings. The perceived comfort ratings are so highly correlated with the vertical rms levels ($r^2 = .896$) that there is little variance remaining to be described by the other descriptive parameters of the ride. This high correlation suggests that any future detailed investigation of the effects of differences in ride characteristics or perceived comfort should equate all of the ride segments so that the average energy along each vibrational axis is the same for all of the ride segments.

Table 5-10. RMS Accelerations at Normal (1.0) Amplitude of the Ride Segments Used in Experiments I and II

Ride	Vertical g rms	Lateral g rms	Roll rad/sec^2 rms
R1 lateral event	0.0475	0.0287	0.0611
R2 continuous rough	0.0384	0.0191	0.0541
R3 roll	0.0530	0.0331	0.0653
S smooth	0.0399	0.0201	0.0542

The differences in the rms amplitudes of the ride segments at "normal" amplitudes apparently has masked any differences in perceived comfort due to differences in the vibrational frequency and event content of the rides. This suggests that future research on the effect of these descriptive parameters on ride quality should take care that the rms amplitude of the vibrations of each ride segment should be normalized to some standard. Alternatively, we may tentatively assume that the major ride factor affecting comfort is the total energy of vibration, and that differences in ride characteristics within the range of rides experienced on a single vehicle is relatively unimportant.

5.5.3.5 Learning Effect

The standard deviation of the subjects' responses to each ride segment are plotted in Figure 5-4 in the order in which the rides were presented (see Table 5-6). Reduced variability in responses to later rides suggests that the subjects used the first four rides to "calibrate" their use of the comfort scale to the expected range of rides.

5.5.4 ANALYSIS OF RESPONSES TO BIPOLAR SCALES OF RIDE ATTRIBUTES

To eliminate the effects of autocorrelation of response data on each ride, only those responses to one level of each ride were used for each subject. The assignments were randomized, so the data base consists of four subject responses to each level of each ride.

The responses on the bipolar scales were found to be correlated with each other (mostly in the range of $r = 0.5$ to $r = 0.9$) and equally to the responses on the comfort scale. The correlation coefficients between the comfort ratings and the bipolar scale ratings are summarized in Table 5-11.

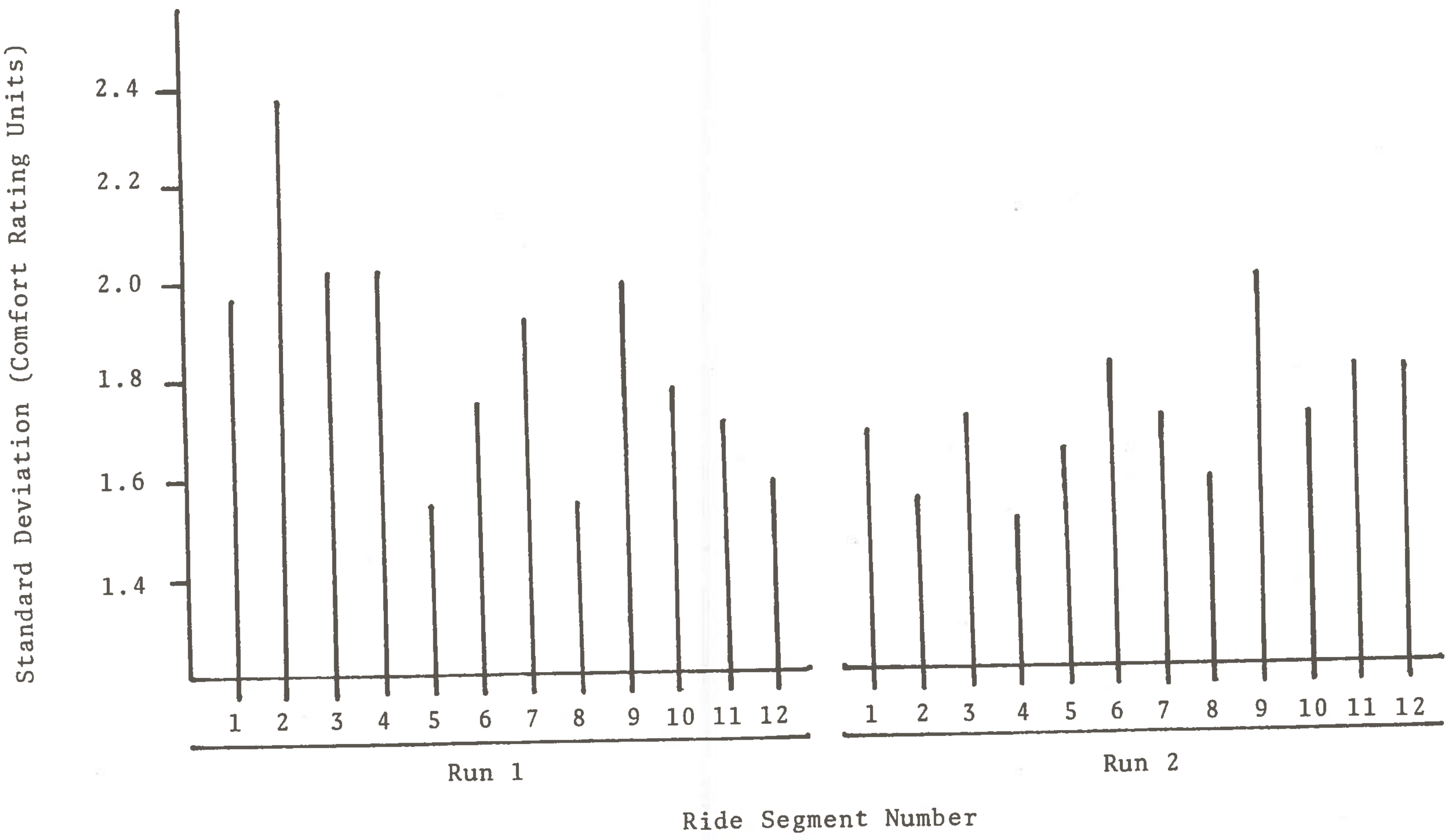


Figure 5-4. Standard Deviation of Comfort Ratings of Each Ride Segment Presentation

Some tentative conclusions can be drawn from inspection of Table 5-11:

> Lateral Event: Comfort is most highly correlated with "annoying"; low correlation with "surging," "rocking," and "bouncy."
>
> Continuous Rough: Comfort is most highly correlated with "jolting," "rolling," "lurching," and "rough."
>
> Roll: Comfort is most highly correlated with "surging," "lurching," "rocking," "bumpy," "shaky," and "bouncy"; relatively low correlation with "annoying," "jerky," and "uneven."
>
> Smooth: Comfort is correlated with "uneven"; rather low correlation with "annoying," "rocking," or "bumpy."

A stepwise multiple linear regression technique was used to determine whether the comfort ratings could be predicted by a linear combination of responses on the descriptive scale. For each of the four rides, the correlation coefficient between the comfort rating and the bipolar scale most highly correlated with the comfort ratio was highly significant ($P < 0.001$).

Table 5-11. Correlation Between Comfort Ratings and Bipolar Scale Ratings

Scale	Correlation Coefficients			
	Lateral Event	Rough	Roll	Smooth
Surging-smooth	.554	.734	.770	.761
Jolting-smooth	.793	.823	.815	.704
Lurching-calm	.822	.828	.838	.729
Bumpy-smooth	.762	.770	.780	.596
Rolling-smooth	.745	.801	.730	.656
Annoying-smooth	.873	.807	.669	.625
Rocking-smooth	.503	.763	.852	.684
Lurching-smooth	.602	.818	.800	.741
Bumpy-calm	.715	.816	.876	.650
Rough-smooth	.840	.879	.852	.712
Shaky-smooth	.714	.825	.848	.723
Bouncy-smooth	.586	.823	.846	.700
Jerky-calm	.729	.736	.525	.686
Uneven-even	.806	.763	.579	.822
Shaky-solid	.846	.783	.885	.705

However, the use of the additional responses obtained from a second bipolar scale to form a regression equation with two explanatory variables (bipolar scale responses) did not result in a significant increase in the multiple r for the regression ($P > 0.1$). Therefore, there is no evidence that comfort is derived from a linear combination of the evaluations of descriptive factors. This suggests that "comfort" is as much a fundamental descriptive parameter of the passenger's evaluation of the ride as are any of the other proposed "descriptive" parameters.

5.5.5 SUMMARY OF RESULTS--EXPERIMENT II

Although the responses on the comfort scale were a reliable measure of the relative comfort of each ride segment, it appears that the subjects use the first few rides to adjust their scale responses to the expected range of rides. This implies that the comfort ratings provide a relative, rather than an absolute, measure of the quality of the ride. The scale units on the comfort scale are approximately linear with the logarithm of the relative amplitude of the ride, suggesting that Steven's Power Law holds for perceived comfort.

The responses on bipolar scales of ride attributes are all correlated with the comfort ratings, but the relative degree of correlation can provide some qualitative insight into the factors which most affect the comfort of each ride.

A weak relationship between the gender of the subject and the responses on the comfort scale was noted, but was not statistically significant. The time of day of the experiment was not found to affect the perceived comfort of the ride.

5.6 CONCLUSIONS AND RECOMMENDATIONS

Subjects have shown a high degree of reliability in rating the relative comfort of rides on a simple unipolar scale of perceiv discomfort. There are, however, significant intersubject differences in the use of the comfort scale. These intersubject differences cannot be explained by either the gender of the subject or the time of day of the experiment.

The scale units of comfort are apparently linearly related to the logarithm of the vibration amplitude, suggesting that Steven's Power Law applies to comfort perceptions. The use of the comfort scale to evaluate relative ride comfort of operational vehicles is limited by the relative nature of the responses--subjects calibrate their use of the scale to cover the spectrum of rides experienced. The descriptive scales were found to give some qualitative information on the differences perceived between rides, but further work will be needed to establish the multidimensional relationships which define psychologically different types of rides.

We can conclude from the experimental evidence that there are no serious methodological problems which limit the study of ride quality. Experimental subjects, and presumably passengers, can reliabily estimate the relative comfort of different vibration environments. Therefore, a comprehensive program of research based on the conceptual models and experimental designs presented in this report should result in an understanding of the relationships between the ride and ride quality. Such an investigation is needed in order to provide vehicle designers and system's engineers with reliable and meaningful guidelines for the development of new and improved surface transportation vehicles.

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APPENDIX A

VIBRATION

The term vibration is used to describe all vehicle motions, accelerations, and jerks which affect the comfort or acceptability of the ride. The vibration may arise from interaction of the vehicle with guideway irregularities, from design motions such as starts, stops, and turns, and from mechanical equipment aboard the vehicle itself.

Vibration may be described in engineering terms as frequency, amplitude, duration, peak acceleration, peak jerk, etc. However, the basic criterion of evaluation of the vibration is the effect which it has on the passenger's comfort or acceptance of the ride. The engineering description of the vibration of a vehicle may not be highly correlated with either the passengers' perceptions of the vibration or their evaluations of the quality of the ride.

The relationships between vehicle vibrations (or whole body vibrations) and ride quality have been the subject of a number of studies over the last forty years. The most comprehensive recent review of the literature is that of Hanes (28) who concluded:

1. There is so little agreement between studies of vertical and horizontal vibration that no region of maximum sensitivity to vibration can be clearly defined.
2. There is little data on interactions between frequencies and axes of vibration.
3. Sensitivity to random vibration seems to vary with frequency.
4. Individual differences in sensitivity are very large and are responsive to procedural differences.
5. Available data gives no basis for choosing any one vibration comfort criterion in preference to any other.

The previous work in ride quality has been concerned with human reactions to specific components of the vibration environment, and measurements of the vibration have been limited to the particular problem under consideration. Those studies where the vibration environment was measured are indicated in Table 3-4.

Most studies of ride quality have considered "comfort" and "acceptability" and quality descriptors along a single evaluative axis. Field judgments of sensation perceived (20), field perceptions of sensation (42), perceptions or judgments of tolerability of sensations, whether in field (38, 52, 83) or simulator environment (63), and comfort level versus acceleration or deceleration level (76, 75, 49, 7, 48) are not comparable because descriptors varied. However, across all studies, subjects rated levels of vibration as unacceptable for riding comfort that they also judged as within the acceptable sensation parameter. Laboratory studies have estimated intolerance at much lower levels than have field studies (62). Head-bobbing due to roll, yaw, and heave added to discomfort (63). Allen compared 13 laboratory investigations with 5 field studies for a band of unacceptable vibration levels. Vibration rated "uncomfortable" in the lab was rated acceptable in the field studies (4). It is apparent that acceptability of vibration is not an indicator of comfort; some vibration has been rated as both unacceptable and comfortable by the same subject sample (76).

Hartgen and Tanner (29) agree that we need to gather both engineering data and passenger attitudes toward a system and evaluate the relationship between them to know what is involved in ride comfort (p. 14).

Ride quality must consider both stimulus and response. Stimulus characteristics are measurable (noise, vibration, temperature, etc.); the human response will be influenced by the system and passenger attitude characteristics (prior experience, expectation, trip purpose, perceived safety, perceived cost, etc.). A passenger's response in terms of ride quality is also influenced by comparison of the vehicle with another one about which he has knowledge and experience (36). Studying the acceptability of vehicle vibration will be misleading if all of these additional factors are not considered.

APPENDIX B

HABITABILITY

For any vehicle, the term habitability is used to describe design components which make the vehicle suitable for occupancy by passengers while the vehicle is stopped or moving. Habitability components of interest as derived from the literature are: (1) noise; (2) temperature; (3) air quality; (4) seating; (5) interior lighting; (6) windows; (7) entrance/exit characteristics; (8) decor; (9) handholds; (10) baggage accommodations; and (11) toilet facilities.

Each of these has well-documented standards which can be implemented by the design engineer. However, one or several habitability components, even when well within acceptable limits, may significantly influence passenger evaluation of ride quality. Any habitability factor, or component, occurring in extreme degree would be prejudicial. It would likely catch attention and mask other habitability factors. A review of the literature indicates that, although all habitability components do not, in reality, interact with those of the vibration environment, they do appear to influence passenger perception of both the vibration environment and ride quality.

1. NOISE

Interior and exterior noise affects passenger evaluation of ride quality. For some vehicles (specifically, hovercraft), power source noice is a major problem; for all vehicles, noice which interferes with conversation is unacceptable. Even at low levels impulsive noise is less acceptable than continuous noise in passenger vehicles.

For most modern vehicles, technology has more or less eliminated vehicle noise as a passenger irritant. For example, changing the clickety-clack sound of a train to clunkety-clunk had no impact on passenger evaluation of ride, although the passengers did indicate a significant difference in perceived noise level (62). The hovercraft seems to be the exception; here, the vehicle noise, more specifically power plant noise, does influence passenger evaluation; Manenica and Corbett (45) did find a correlation between noise acceptability and passenger comfort ratings.

Passenger criteria for acceptability of vehicle noise seems related to the degree to which noise interferes with a desired activity such as conversation. Visitors to the TRANSPO exhibit (13) made no reference to vehicle noise but were concerned about crowd noise, the poor sound level of the speaker system and the exterior noise produced by operation of one PTPRT. Schlegel, Stave and Wolf found no significant differences in passenger perception of noise, if the level present did not interfere with conversation (62). McFarland and Stoudt (44) suggest application of currently existing criteria for noise interference with normal speech as criteria for acceptable vehicle noise. SEPTA survey respondees (81) seem to agree; while less important than having a clean seat, low noise vibration was ranked fifth in both importance and comfort scales. It seemed that they preferred some low background noise, provided that conversation and other activity was not interfered with.

Carstens (12) maintains that noise annoyance is subjective, depending on familiarity with type and intensity level of the perceived noise. He would, therefore, expect intermittent or impulsive noise to be more annoying than constant ambient noise; impulsive noise due to helicopter rotor blade functioning has been judged more annoying (62). Moreover, passenger judgments of annoying impulsive noise levels showed sensitivity about 5.5 perceived noise levels (PndB) below the perceived noise level expected.

Noise has also been used as a standard in determining the correspondence between judges' ratings and vibration intensity. Van Deusen (78) had riders in military trucks adjust white noise levels to equal the subject's perceived level of ride discomfort. By thus applying cross-modality matching, Van Deusen and others (51a,b,c, 64, 65) felt that a subjective vibration intensity scale could be developed using Stevens' power law. Knowing the physical intensity of both noise and vibration stimuli, and the exponents of the power function relating the physical intensity of noise to its sensation magnitude, Van Deusen would then compute the exponents of the power function for vibration. He got good correlation between subjective uncomfortableness as measured by white noise intensity and jerk, but for all other vibration components the correlations were non-significant. An earlier experiment (77) produced much the same results, which Van Deusen attributes to the effect of masking.

2. TEMPERATURE AND AIR QUALITY

Both general temperature level and variations in temperature co-react with air quality in producing acceptable habitability for a vehicle.

Air quality includes humidity, air pressure, ventilation, variations in these three and the presence of odors, smoke, etc.

Temperature and air quality were judged very important by bus and train riders (No. 2 of 5 habitability factors in importance, Shirley Bus Survey, [61]; and No. 3 in importance of 11 design factors, Southeastern Penn Transportation Authority, [81]). Hovercraft passengers, who as previously noted were subjected to unacceptable noise, rated these factors No. 7 in importance of 18 vibration, habitability, and operational factors listed (58). Since standards for acceptable temperature, humidity and ventilation parameters currently exist (62, 12), these problems will presumably be eliminated in future transportation modes. Cost would presumably be the only barrier to air conditioning for all future high-speed vehicles.

Carstens (12) and McFarland and Stoudt (44) are concerned about air pressure changes and the rate of increasing or decreasing ambient pressure in future modes. Problems similar to those previously found in unpressurized aircraft can be expected as high speed trains, tubes, etc., enter and leave tunnels or shafts (46). However, the technology needed to control interior pressure, already well developed for aircraft, should be applicable.

3. SEATING

Seat size, conformation with human morphology, head and arm rests, and the amount and quality of padding all affect passenger comfort. Adequate leg room, and enough physical space on all sides to allow the passenger to engage in desired activities without feeling crowded or uncomfortable, must also be considered when designing and locating seats within vehicles.

Seat comfort seems to be as important a design acceptability factor as "having-a-seat" is a mode acceptability factor for modern transportation users. Gebhard sees the automobile seat as one reason for the acceptance of higher vibrations of all types by automobile users (22). In designing the BART (Bay Area Rapid Transit) system, it was felt that riders would be unwilling to trade the car seat, especially the bucket seat, for the usual mass transit seat (44).

Having-a-seat--Riders of the prototype PTPRT and air cushioned vehicles at TRANSPO (13) objected to the lack of seats for all passengers. Since TRANSPO visitors represented a population that rarely uses public transportation (13, p. 59), this may be a car-related bias. However, in the South Eastern Pennsylvania Transportation Authority Survey (81), users also rated having-a-seat as most important. Once that need was met, then comfort was important. In order to have a seat, peak traffic period respondents preferred the 3-2 seat arrangement, even though they felt crowded under these conditions. Off-peak period travelers also preferred the 3-2 seat arrangement; not because they then had a seat, but because the extra seats went unoccupied, thus providing them with more seat space. Given a seat, these commuters would then opt for: (a) a comfortable seat; (b) a clean seat; (c) more roominess (width) and leg room; (d) seats facing forward (81, p. 9).

Seat Comfort--There are purely physical reasons for placing some emphasis on seat comfort. A passenger in a relaxed position tends to rate ride quality more favorably (63). A well-designed seat makes it easier for passengers to unconsciously adjust to sway, thus avoiding some fatigue over long trips (8). Branton and Grayson (8) found that firmer seats led to better sitting posture and less squirming and fidgeting among train passengers.

Men seem to prefer wider bus seats and more leg room (61) as would be expected due to their physical size. Designing seats to accommodate the morphologically extreme members of the passenger population is suggested by McFarland and Stoudt (44) as one way of increasing seat comfort and therefore ridership. However, Manenica and Corlett (45, p.850) quote Shackel, who found no agreement between ergonomists' ratings of seat comfort after measuring the seats with the comfort ratings of subjects sitting in the same seats.

Crowded Seating--Here the results of prior investigations are contradictory, perhaps vehicle specific or based on expectation. Urabe and Normura (75) found that in trains a crowded seated position led to greater tolerance of vibration. However, hovercraft passengers were more annoyed by crowded seating than by noise and vibration (58).

Forward-facing Seats--Car passengers who face forward accept much higher levels of lateral acceleration than train or trolly passengers (22). Therefore, the SEPTA passengers' preference for forward-facing seats (they would face rearward in order to have a seat, especially during a rush hour) may be due to a reduction in discomfort resulting from lateral acceleration (81). However, Matsui (49) found that, at the same level, lateral acceleration was equally unacceptable in both forward-facing and side-facing train seats.

4. INTERIOR LIGHTING

This includes both general over-all illumination and specific lights within the vehicle, i.e., reading lights.

Few studies currently available deal with interior lighting as a significant factor. The Penn railroad study (81) shows interior lighting of medium importance. Shirley bus passengers did not show any significant preference for decorated translucent panels over normal bus lighting, and most respondents (70%) considered improved lighting unimportant (61). Only air travelers seem to consider lighting important;, in this case, the importance of lighting may have been due to the most preferred passenger activity: reading (37).

5. WINDOWS

Window size, location, and the availability of shades or blinds seem to interact with each other in influencing passenger perceptions of luxury, spaciousness, and safety, as well as satisfying preferences for privacy and the ability to perform desired activities (i.e. looking out, reading).

Large windows placed to allow "viewing out" were perceived as attractive and important to passengers of the RRT, PTPRT, monorail and bus (13), train (81), hovercraft (45) and short-haul aircraft (37). In fact the Swansea hovercraft study showed "inability to see out because of spray" to be the most frequent complaint received (58).

Both Carstens (12) and McFarland and Stoudt (44) show concern about flicker frequency effects (nausea, tremors, etc.) due to poles, trees, etc. too near the guideway of modern high speed ground vehicles. Shades or slanted blinds used by train passengers to counteract sun glare (ranked #7 of 11 design factors in SEPTA Study (81)), could also be effectively used to counteract flicker.

6. ENTRANCE/EXIT CHARACTERISTICS

Size, location, the amount and kind of lighting available and accessibility either by stairs, ramp or a platform level with the waiting area comprise the characteristics most frequently mentioned.

The importance of vehicle access or egress is not too relevant to the general population. However, Golob, Canty and Gustafson (24) did find differences between their total sample and the elderly and low income groups for the proposed Jitney service. Comments on the narrow doors of the PTPRT's and monorail at TRANSPO (13) which made carrying packages aboard difficult may explain low income respondents' preference for easy access/exit. The hovercraft passengers surveyed at Swansea (58) required more emergency doors, perhaps because of their unfamiliarity with the mode.

7. INTERIOR DECOR

Floor and seat covering, color scheme, light fixtures, attractiveness of materials and positioning of seats, lights, etc. comprise the most important aspects of interior decor. Passenger perception of decor, however, also involves cleanliness. Although transportation users respond favorably to new vehicles (13, 64, 61, 81) vehicle decor ranks low in importance to train (81) and Jitney users (24). Passengers on the Shirley Highway express buses did rate the absence of advertising as a most satisfactory feature (61). However, all features of these buses were rated satisfactory by users.

8. HANDHOLDS

The structure of the handholds themselves plus their visibility, availability, the number available, and their location (seat back suspended, poles, at entrance/exit) enter into passenger vehicle evaluation. Most mass transportation vehicles will at some time have occupants who are either standing or walking. Hirshfeld (31) in his laboratory studies of standees on a street railway car has given us some excellent starting points. However, his single criterion of discomfort during acceleration was change in a set standing posture. This posture may not have been the most advantageous for his subjects who varied in age, size, and sex.

McFarland and Stoudt emphasize the necessity for accommodating extreme ranges of the passenger population (44, p. 169). Most TRANSPO visitors preferred overhead hand-holds (13). However, both poles and seat back holds might be more useful to short, elderly or walking occupants (32). The most important finding of the passenger/prospective passenger surveys was that, even though they want readily available handholds, most people do not want to stand in any vehicle (13, 61, 81, 24).

9. BAGGAGE ACCOMMODATIONS

Amount of space provided, both adjacent to a seat and in other locations, and accessibility both in route and upon arrival are important. Passengers may also require assistance in handling baggage, and short waiting periods to check baggage in or out are also advisable.

Visitors to TRANSPO were unhappy with the PTPRT and monorail prototypes because of their inadequate baggage or package space (13). Wahmann and Fleischman's survey (81) indicated that both peak and off-peak period train passengers were interested in having baggage racks available. Prospective users of a proposed Jitney service (24) were, however, willing to have less baggage space if fares were lower. Hartgen and Tanner's survey population (29) also felt that baggage space was relatively unimportant.

10. TOILET FACILITIES

The most important factors here were availability, accessibility and cleanliness.

No survey respondents showed any strong preferences in regard to toilet facilities. The SEPTA passengers (81) ranked them #8 out of eleven vehicle attributes.

CONCLUSIONS

Studies were reviewed for several vehicles, although the largest number involved trains and buses. We would expect some variations in factors judged as important as a function of vehicle type. However, as a general summary across subjects, the most important habitability factors appear to be:

Seating, especially availability and cleanliness
Noise factors
Air temperature

Next most important are:

- <u>Air Quality</u>
- <u>Windows</u>
- <u>Handholds</u>

APPENDIX C

OPERATIONAL FACTORS

The third class of factors that influence evaluation of ride quality are referred to as operational factors, i.e., how vehicles are guided, how passengers are treated, headway, accident records, etc. The basis for distinguishing between operational factors and vibration and habitablity is that design engineers have little or no control over operational factors. As with vibration and habitability, operational factors can be quantitatively measured and rider perceptions and evaluation obtained by attitude scales. Also, as with vibration and habitability, objective measurements of operational factors do not necessarily correlate highly with passenger perceptions of these factors. We have, for example, the costs of the ticket versus perceived costs; safety as measured perhaps by number and severity of accidents over a time period, as compared to perceptions of safety; headway versus the passengers' perceptions of their waiting times, etc. An extensive list of operational factors was reviewed from the literature survey. These factors are summarized in Table III-1.

Although the operational characteristics of the various travel modes are not of direct concern to this research, passenger perception and evaluation of these likely interact with perceptions of habitability and vibration. In some cases, putative operational characteristics are the main determinants of system use. Operational characteristics which prior studies indicate have had a major impact on both perception and choice of transit mode are convenience, cost, and various time factors. Norman and Louviere (56) had subjects rate prospective bus systems in terms of cost (fare) and convenience (frequency of service, distance to bus stop). Both cost and convenience attributes had a significant effect on probability of use, as did interaction between those attributes.

APPENDIX D

HUMAN FACTORS INFLUENCING RIDE-RIDE QUALITY CRITERIA

The literature reviewed indicates that these characteristics of users of transportation systems may influence evaluations.

1. Demographic factors
2. Trip Purpose: Passenger purposes in making a trip.
3. Prior experience of passengers/evaluators.
4. Set: the needs, attitudes and expectations of passengers which seem to influence vehicle mode ridership and evaluation.

In preparing to study passengers of operational vehicles, these factors may be regarded as potential controls, or as descriptors of subject populations.

1. DEMOGRAPHIC FACTORS

The sample population, in order to represent the general transportation system user/prospective user, should take into account:

Age

Sex

Social class, or subclass

Income level

Urban, suburban, rural household location

Physical characteristics influencing use or non-use of mass transit (i.e., physical disability).

Prior investigations leave gaps in knowledge of both user and non-user populations, according to Hoag and Adams [32]. However, the reviewed literature indicates that the acceptability of various vehicle modes is related to:

> The physical size, strength and mobility of the traveler population [7, 37, 44];
>
> Psychological profiles of individuals and groups; i.e., householders [37] or social class [29];
>
> Subjective evaluations of vehicle or system characteristics [32].

EFFECTS OF NON-REPRESENTATIVE SAMPLES

Subject samples in both simulator and field studies may not be representative of vehicle users, either due to specific study requirements or because in some cases investigators do not know what a representative sample would be. Particularly in field studies aboard trains, select population samples may partially account for the lack of correlation inconsistencies and reversals of findings between studies.

The AAR study [20] as well as the British [42, 83] and Japanese efforts [38,47-49,51,52,75,76] confined their sample populations to male engineers or engineering students and railroad personnel of varying ages, which they frequently do not specify. A sample population that clearly differs from the average population of riders may also affect results of simulator studies [23, 60, 63-67] and their applicability/transferability to either field studies with controlled populations (such as British, Japanese) or to surveys among fare-paying passengers. Work currently in progress at NASA attempts to obtain more representative samples, within the stringent limitations of its apparatus [15,19,72].

Age

Age very definitely influences size, strength and mobility with resultant differences in vehicle ride quality evaluation. Aisle width, step height and vehicle entrance/exit configuration have been shown to be important to the elderly and to the very young [32, 44]. Older people give more favorable ratings than the general population to PTPRT's without steps, buses with low steps, and vehicles having more seat space and better provisions for standees [13].

Previous investigators disagree about the sensitivity of various age groups to the vehicle vibration environment. Halloway and Brumaghkin found that sensitivity to vibration did vary, even within their highly selected small age-range sample [27]. However, Dempsey and Leatherwood [19] and Hirshfeld [31] found that age had little or no effect on response to vibration parameters. However, in view of the fact that the young non-driver and the elderly are more apt to use mass transportation [24], their inclusion in user surveys seems relevant.

Sex

Sex differences in human response to transportation modes seem more apparent for habitability components. Men have a significantly greater preference for larger, more padded seats, more leg room, wider aisles and wider, taller entrance/exits, regardless of vehicle mode being studied [13, 26, 61]. Additionally, Branton and Grayson [8] found differences in sitting behavior. Men slumped, used arm rests, stretched their legs out and changed position more than women. At the present time it is unclear whether a man's behavior is influenced by available seats or whether his preference for larger, roomier seats is a function of his sitting behavior.

Women, while expressing no significant preference for seats, leg room, etc., do show marked concern for other habitability components. Their emphasis is on components related to "shopping": entrance/exit characteristics, package space, aisle width and between-seat distances are unacceptable if they make such shopping difficult [13, 44]. Hoag and Adams [32] indicate another factor in their concern: women, who are frequently accompanied by small children, also require many of the same attributes to make travel with children easier. These two functions, shopping and traveling with children, may be the reason Hall and Sarti [26] found that, as the number of drivers per household increased, it is usually the male worker who uses public transportation.

Neither Dempsey and Leatherwood [19] (using a simulator) nor Hirshfeld [31] (in a laboratory trolley) found that men and women respond differently to vibration stimuli.

Social Class

Social class or subclass is felt by Hoag and Adams to influence vehicle evaluation [32]. For example, in Jacobson's studies of air traveler populations, comfort seemed to be a function of the ability to perform their most desired activity, reading. It, therefore, involved steadiness, comfortable temperatures, absence of smoke and noise, plus adequate lighting and work space at each seat [37, 39, 41]. For the most part, Jacobson's population was composed of professional people and business managers; Wahmann and Fleishman's train population [81], which had a much broader social class spectrum, was primarily concerned with having a clean seat.

Social class also seems to influence residential patterns, number of cars per household and family activity patterns. All of these factors influence both choice of vehicle and perception and evaluation of ride [22, 29, 33, 40, 57].

Public transit passengers are heterogeneous. Byrne, Freedman and Doob [32 p. 130] report data indicating that people seek to avoid those perceived as different from themselves. Their findings agree with those obtained during TRANSPO interviews [13].

TRANSPO visitors were primarily middle class. When shown a picture of an "unsavory" person and asked to respond [13, p. 67, 68], to "what do you think?", 59% gave negative responses about riding with him.

Income Level

Passenger income level affects tolerance for both vibration and habitability. Lower income riders accept more vibration and poorer habitability, perhaps because they have no alternative [24]. Passenger expectation of cleanliness and comfort increases as income level rises [27]. At higher income levels, travelers prefer their personal car to public transportation [26] in spite of greater vibration levels in cars.

Urban/Suburban/Rural

No significant effects were found here, although rural residents visiting the TRANSPO exhibit seemed to respond more positively to new vehicle designs [13].

Physical Disability

Several studies have identified special requirements of the aged and elderly using public transportation systems [1,2]. The most important of these requirements are concerned with access and seating while the ride of the vehicle is, in comparison, a relatively minor factor.

2. TRIP PURPOSE

The ride which is evaluated in ride quality research may be an entire trip, P/O to P/D (point of origin to point of destination), or it may be only one portion of a given trip. Passenger evaluation of ride may be influenced by passenger evaluation of or attitude toward the entire trip. Therefore, in obtaining ride quality evaluations, we would want to know both trip purpose and the extent to which trip purpose correlates with differences in ride quality evaluation.

Hall and Sarti [26], Paine, et. al. [59] and others (i.e., 13,81) have made a distinction between work and non-work related travel.

Since work/non-work has been the major discriminant in most prior studies reviewed, we have divided trip purpose into the same two categories, with some subclassifications in the non-work category:

Work

Non-work
-- Shopping, personal business
-- Social, family activities

To/From Work Trip

Passengers who are able to choose between various vehicles do so in accordance with self-determined criteria for a particular trip. The requirements for vehicles used to and from work vary depending on type of work, location of work site or sites, and non-work related activities infringing on to/from work trip. A craftsman required to carry bulky tools or an outside salesman would be more concerned with the ability to carry his equipment conveniently or with ease of commuting from one work site to another [26]. Hartgen and Tanner [29] found that the purpose of a trip affected consumer judgment as to the acceptability of vehicle characteristics; "choice of mode is a probability function of the traveler" [5, p. 36]. The to/from work population is most likely to use one particular mode and, therefore, is more concerned with its ride quality [26, 61].

Wahmann and Fleishman [81] indicate that trip purpose and time of day influence train passenger ratings of attribute importance. Peak hour travelers stressed the importance of having a seat; off-peak passengers with typically different purposes were more concerned with other items, since adequate seating was available. Normally, workers select the vehicle providing the fastest route when making to/from work trips [5, 26, 59, 81]. However, work/non-work distinctions also exist in the trade-offs users are willing to make (i.e., longer trip time if cost decreases [74], or choice of more expensive mode for longer trips because of increased comfort, etc. [35]. Moreover, prospective passengers' misconceptions, relative to time and cost factors involving a particular trip, influence vehicle choice and are probably the cause of the preference for the automobile [4], [32].

It is likely that we would get a more valid evaluation of ride quality from users more familiar/experienced with the mode being studied. Commuters would be using the vehicles more frequently, would have "seen" them under extreme conditions and would be less likely to be influenced by one malfunction. However, they could be biased by habitual use and strong commitment to that mode [5,29,32,33,40,41,59].

Non-Work Trip

Requirements and vehicle choice also vary within the range of non-work trips. For example, a woman going shopping requires parcel space [13] and presumably less waiting time and less distance between a store or stores and the trip vehicle [26, 27, 59]. Respondents in the transportation survey [13] found monorails unacceptable for shopping due to door size.

Non-work travelers are more critical of seat configuration, noise, cleanliness, etc., than those using the same vehicle mode to commute to work on railroads [81], and buses [26,5].

Men are frequently constrained from use of public transportation on family social outings by concern for the safety of family members. Respondents in the Denver [26], Rochester [29], and G.M. Jitney [24] surveys could not use mass transportation for social and family activities, especially at night, presumably because of fears for safety related to other passengers, waiting time at terminals, stops or transfer points, etc. [32].

3. PRIOR EXPERIENCE

Passengers probably establish norms and expectations for a particular vehicle based on prior experience. The more prior experience, i.e., the stronger these norms, the more firmly they are internalized and the less we would expect a given ride to influence the norms. On the other hand, if a passenger had never ridden the vehicle before, he would have no firm prior norms and the single ride would be more influential in determining such norms.

Prior experience may involve these functions:

1. Habit strength regarding a vehicle mode or modes, influenced by passenger flexibility and adaptability.

2. Passenger perceptions and expectations of various modes.

3. Duration of travel in current or other vehicle mode. This may be duration of a ride or duration of a trip of which the current ride is a portion.

It seems reasonable to assume that the more frequently a passenger chooses a mode, the more likely he is to have made some accommodation to that mode. The more negative the evaluation of a user, the higher probability that there is no other convenient way to get to the destination. Therefore, an accommodation is made even though ride evaluations are not good. Gebhard makes the point that automobile users routinely accept jerks, bumps, and bounces that are totally unacceptable to them in trains, buses, trolleys, etc. [22, p. 33].

Correlations between attitude scales (and evaluations of buses and cars) showed a positive link between prior experience with a vehicle and preference for it [28, 5]. Additionally, it has been found that continued use of a vehicle builds a firmer commitment to it [37, 61, 16]. Aslakson found that travelers most familiar with a vehicle type tended to perceive, and thus judge its attributes more favorably, than those of less familiar vehicle types [5], regardless of their similarity or dissimilarity.

Prior experience may bias prospective users toward new modes or new vehicle design because the new vehicle contradicts previously acquired negative perceptions of mass transportation (i.e., smelly, dirty, crowded, etc. [13]).

Duration of travel has been found to negatively affect judgments of ride quality [62].

4. SET

Set is a readiness to perceive the environment in a certain way. Induced by previous experiences, it may be held over in succeeding situations for which it may or may not be appropriate.

In the ridership context, set sensitizes passengers to certain stimuli. It seems reasonable to assume that prior experience as a passenger would help create among experienced riders a set of expectations for ride in a particular mode or type of vehicle. This set, in turn, may provide a norm or norms by which a passenger riding a vehicle would evaluate V, H and their components, and ride quality in general.

Much of the American public is unwilling to use trains or buses. For evidence, one may study the rapid shift in number of mass transportation users before, during, and after the spring 1974 energy crisis. This is circumstantial evidence that transit vehicle use is in part determined by experience and cultural factors, as well as by the means of transportation available. One would imagine that users of the wildly careening, overcrowded Manila jitneys would be most pleased by the METROBUS, which D.C.

area residents cannot be persuaded to use. Acceptance of vehicles and their ride quality is, to a large part, determined by the means of transportation available [24]. It also seems to depend on inter- and intra-passenger needs and expectations, within which man's interaction with the auto and its satisfaction of his hierarchical need system has produced major changes [11,9]. Producing successful (used) transportation systems is not possible unless man's need scale is taken into account (cf. Hoag and Adams [32]). Hoag and Adams also make the point that designers must take both user and non-user preferences into account.

A need seems to exist among transportation users for protection from infringements on what they consider personal space (cf. Byrne 1971 [82]). This notion, personal space, which is unique per passenger, involves self perceptions and preconceptions of his own status, class, self worth, etc., both independently and in comparison with other vehicle users. Researchers have shown (Somer, [71]) that individual personal space varies with felt needs at any specified point in time.

Attitude and expectations based on attitude influence use of a vehicle mode. "Traveler attitudes and perceptions affect judgments of comfort, convenience, personal safety and self esteem resulting from choice of a vehicle" (Hartgen and Tanner [29]). An individual has a set of needs defined by the roles he assumes in his interactions with other persons and groups. He is aware of the various means of potentially satisfying his needs and is predisposed by attitude in responding to the various means (i.e., he reacts to new systems of transportation according to his experience with old systems)[29]. Miyoshi and Sakamoto [52] account for the variations between their panels by citing the individual biases within and between groups about the vehicle and trip. O'Borne and Clarke (hovercraft, helicopter), also felt respondents' ratings were dependent on attitude toward the trip and state of mind both at onset of and during a trip [58, p. 856]. Older people, accustomed to vehicles of poorer quality, are more accepting and enthusiastic about new buses and trains [13, 24].

Shirley Highway bus passengers, surveyed during a very environment-oriented period, were concerned not only with air conditioning, etc., but with obtaining a reduction in exhaust emissions [61].

It would seem that attitudes and expectancies, based on real or perceived factors to which passengers are currently attending, influence their judgments of vehicle ride quality [4, 13, 47, 76].

The finding that non-work trip passengers are more critical of noise, cleanliness, crowding [81, 26, 5] also illustrates the importance of set, not only that related to the vehicle but that produced by trip purpose. Such results lend credence to Gebhard's belief that individual responses depend greatly on what an individual expects or thinks is expected of him [22, p. 37].

CONCLUSIONS

Studies were reviewed for several vehicles, the largest number of which referred to trains and buses. We would expect variations in factors judged as most important, as a function of vehicle type. However, as a general summary across subjects, the most important human factors seem to be:

Set, expectations

Prior experience

Trip purpose.

Next important are:

<u>Income level</u>

<u>Sex</u>

<u>Age</u>.

APPENDIX E

DESCRIPTION OF RIDE SEGMENTS USED IN THE DEVELOPMENT OF PSYCHOMETRIC SCALES

E.1 SOURCE OF DATA

Four separate segments of ride data were selected for use in developing psychometric scales. The vibration data used to program the NASA Passenger Ride Quality Apparatus was recorded during a test run of the FRA track geometry car on the North-East Corridor on August 29, 1974. The track geometry car is a Budd Silverliner passenger coach which has been converted into an instrumentation car. This car contains traction motors and draws the power for locomotion from the overhead catenaries. The top speed that has been achieved by this car on the Northeast Corridor trackage has been in excess of 135 mph.

The vibration data was recorded using the FRA Portable Ride Quality Apparatus that was developed by ENSCO. This device measures accelerations in all six degrees of freedom and records the accelerations on seven-track analog magnetic tape. The Portable Ride Quality Apparatus was operated by ENSCO personnel during a normal track geometry test. The accelerometer package was placed on the floor over the A end truck. There was no cushioning between the accelerometer package and the floor.

E.2 DESCRIPTION OF TEST ZONES

The choice of ride segment was based on a review of track geometry data for the Northeast Corridor. Track segments were selected that were typical, but significantly different from each other. The ride of the test car was recorded while the test car was southbound on the Northeast Corridor track. All of the ride segments were recorded in the vicinity of Princeton, New Jersey. The specific details of the segments are as follows:

S. SMOOTH RIDE

A two-minute section of ride recorded between MP-52 and MP-49 (three to six miles north of Princeton Junction). Train speed varied from 76 to 86 mph. This is all essentially tangent track, the maximum curvature being less than 1/4 degree. The rail is continuously welded, and the track in this area is, by general consensus, one of the best maintained and smoothest sections on the Northeast Corridor.

R1. LATERAL EVENTS

A 44-second section of ride recorded between MP-47 and MP-46. This section of track includes three switches at the entrance to the Princeton Junction Yard. The test car passed over these switches without changing tracks. However, the alignment of the switches was such that a significant lateral displacement occurred at each switch. The Lateral Event ride consisted of two exposures to this 44-second segment of ride, the segments being separated by a 5 to 10 second gap.

R2. CONTINUOUS ROUGH RIDE

This 120-second segment of ride was recorded between MP-72 and MP-68 at speeds varying from 79 to 89 mph. Maximum curvature is 1 degree 11". This section of track is significantly rougher in profile (vertical alignment) than that between MP-52 and MP-49.

R3. ROLL COUPLED VIBRATION RIDE

A 50-second segment of ride recorded between MP-42 and 41. This section included the Monmouth Jct. Yard. The switches and lateral track alignment through this yard caused a series of lateral displacements which resulted in lateral roll of the test car. The 50-second segment was always presented twice, with a 5 to 10 second gap between presentations.

E.3 PRESENTATION OF THE RIDE ON THE SIMULATOR

The amplitude of the vibration on each of the axes was changed during the experiments to achieve a greater variety of rides. In each case, the characteristics of the ride were unchanged, and only the rms amplitude of the vibration was different. The normal (1x) rms amplitudes of the accelerations for each of the rides are summarized in Table 5-1. An analog presentation of the time history of the RMS vibrations for each ride is shown in Figures V-1a through V-1d. Details of the modifications made to the vibration amplitudes during the experiments are included in the body of this report.

Table E-1. RMS Accelerations of the Ride Segments at Normal (1.0) Amplitude

Ride	Vertical g rms	Lateral g rms	Roll rad/sec^2 rms
S. Smooth	.0399	.0201	.0542
R1 Lateral Event	.0475	.0287	.0611
R2 Continuous Rough	.0384	.0191	.0541
R3 Roll	.0530	.0331	.0653

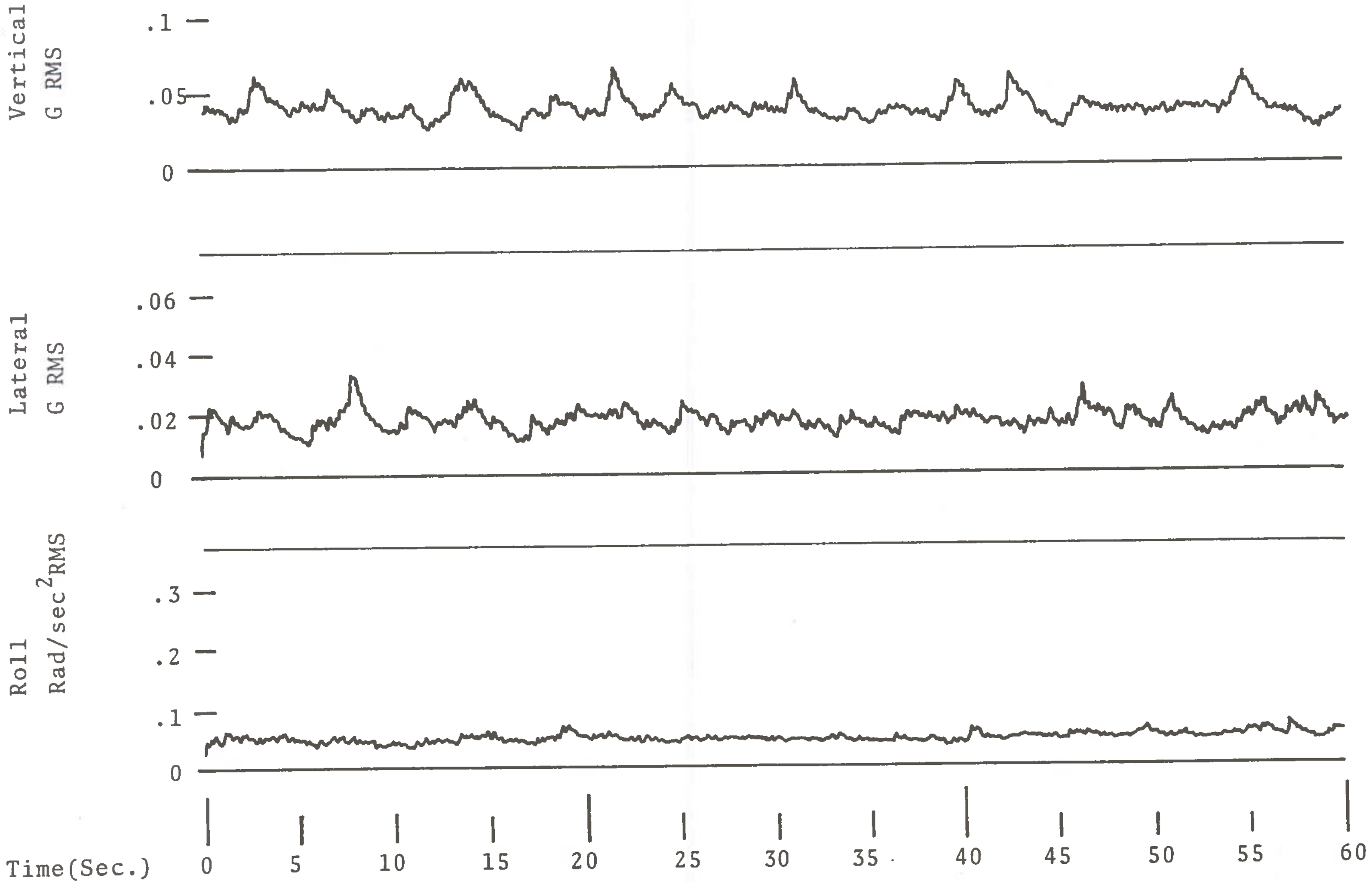


Figure E-1a. RMS Acceleration Time History
Smooth Ride

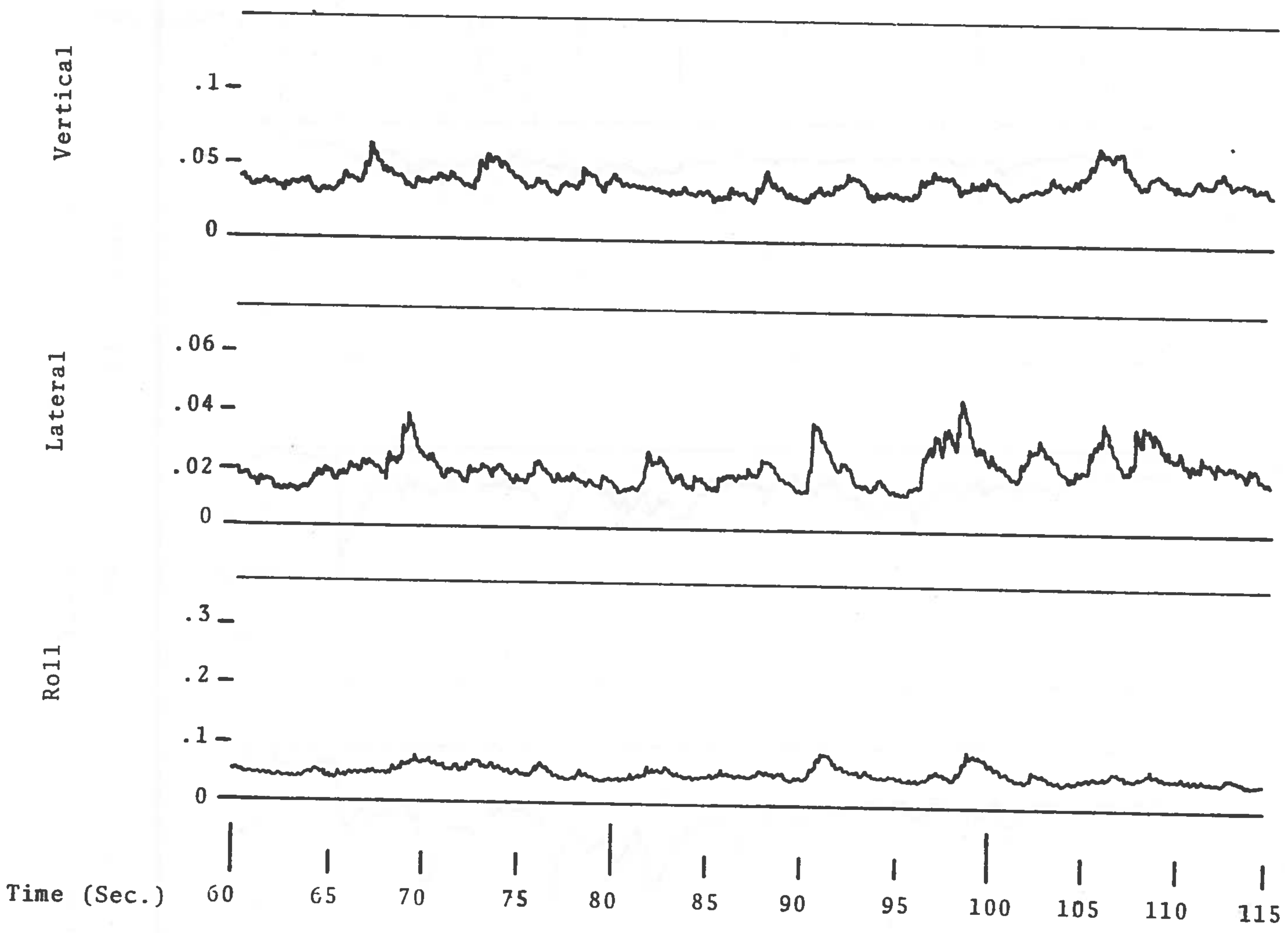


Figure E-1a. (Continued) Smooth Ride

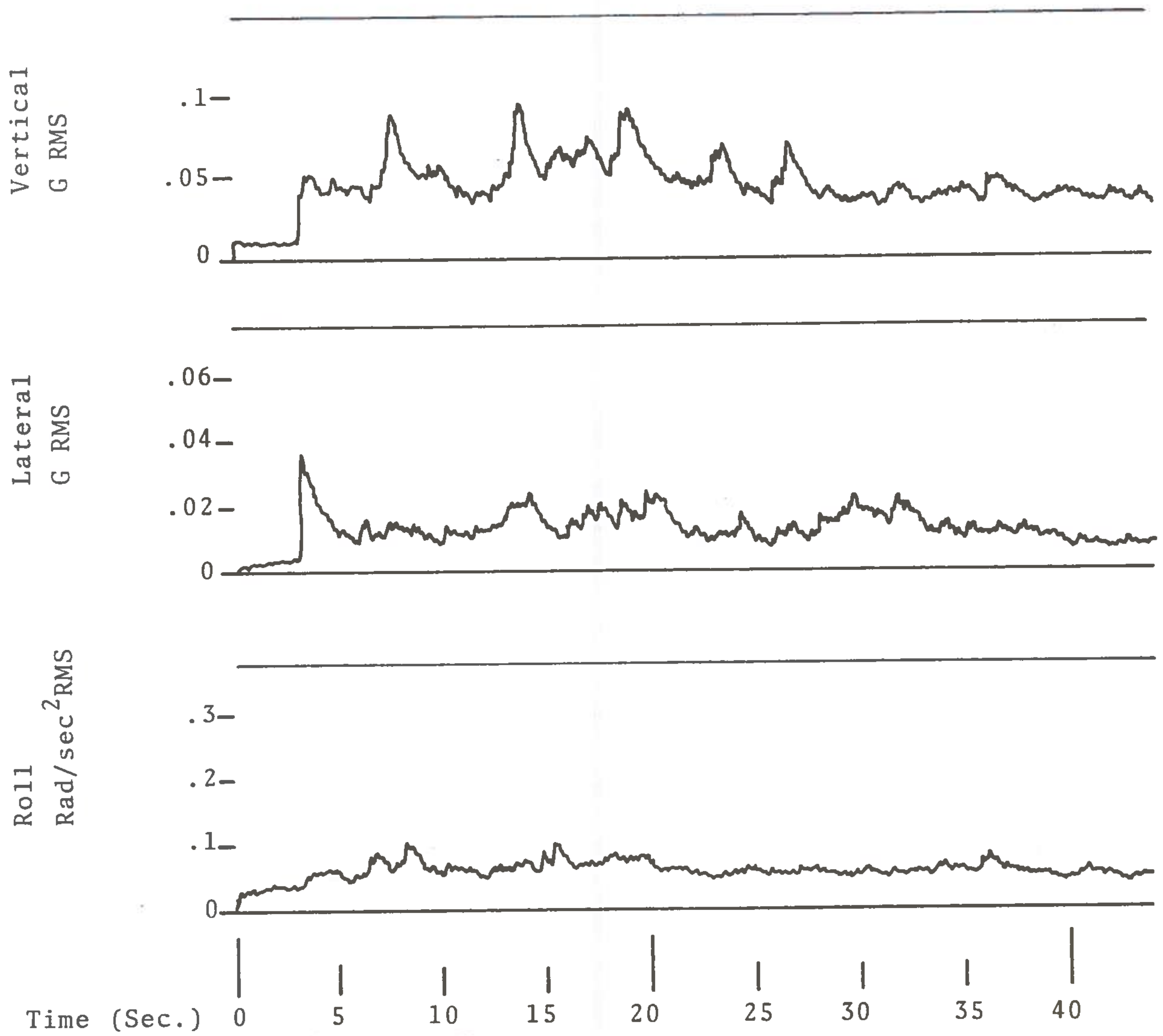


Figure E-1b. RMS Acceleration Time History
R1-Lateral Event Ride

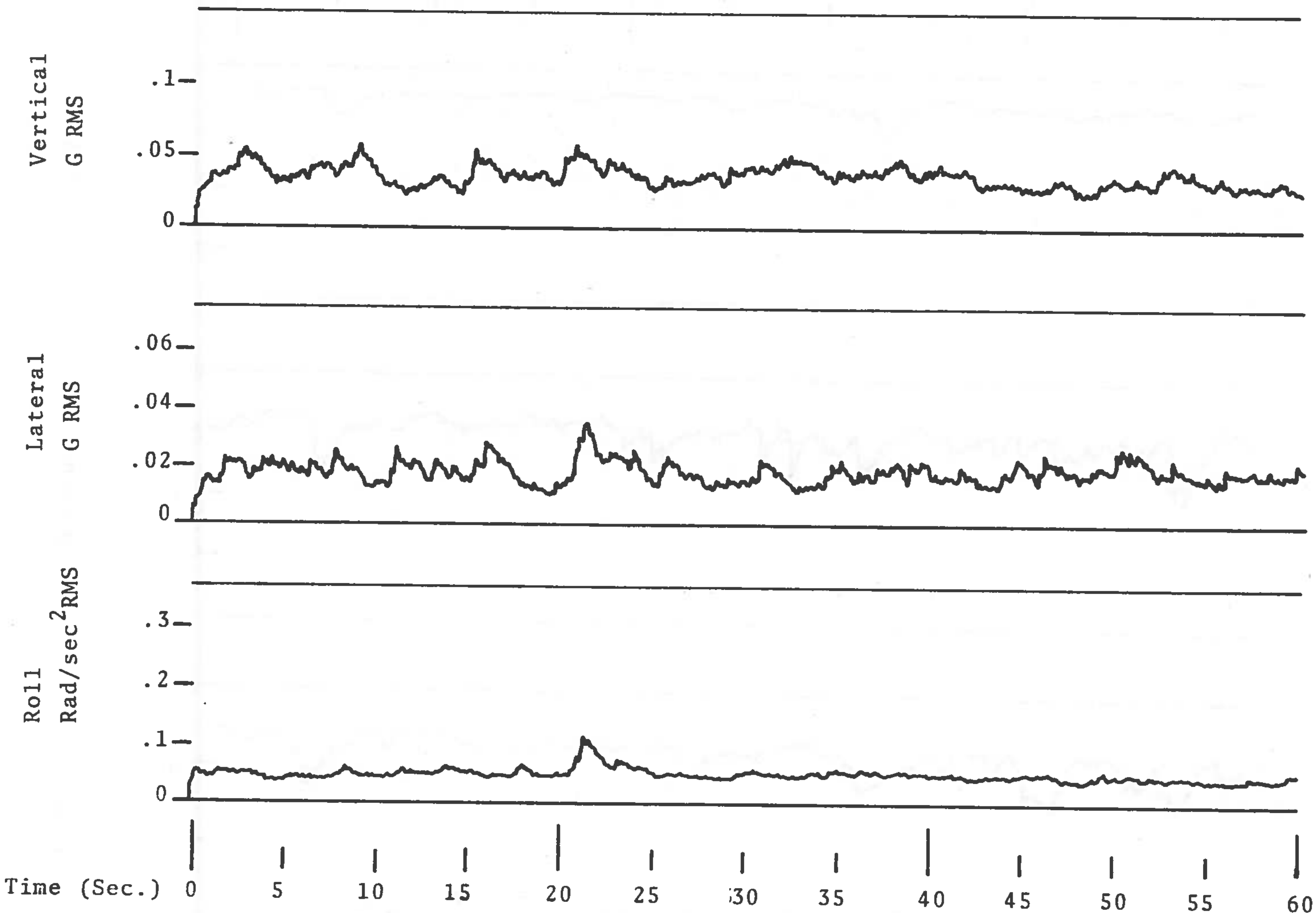


Figure E-1c. RMS Acceleration Time History
R2 - Continuous Rough Ride

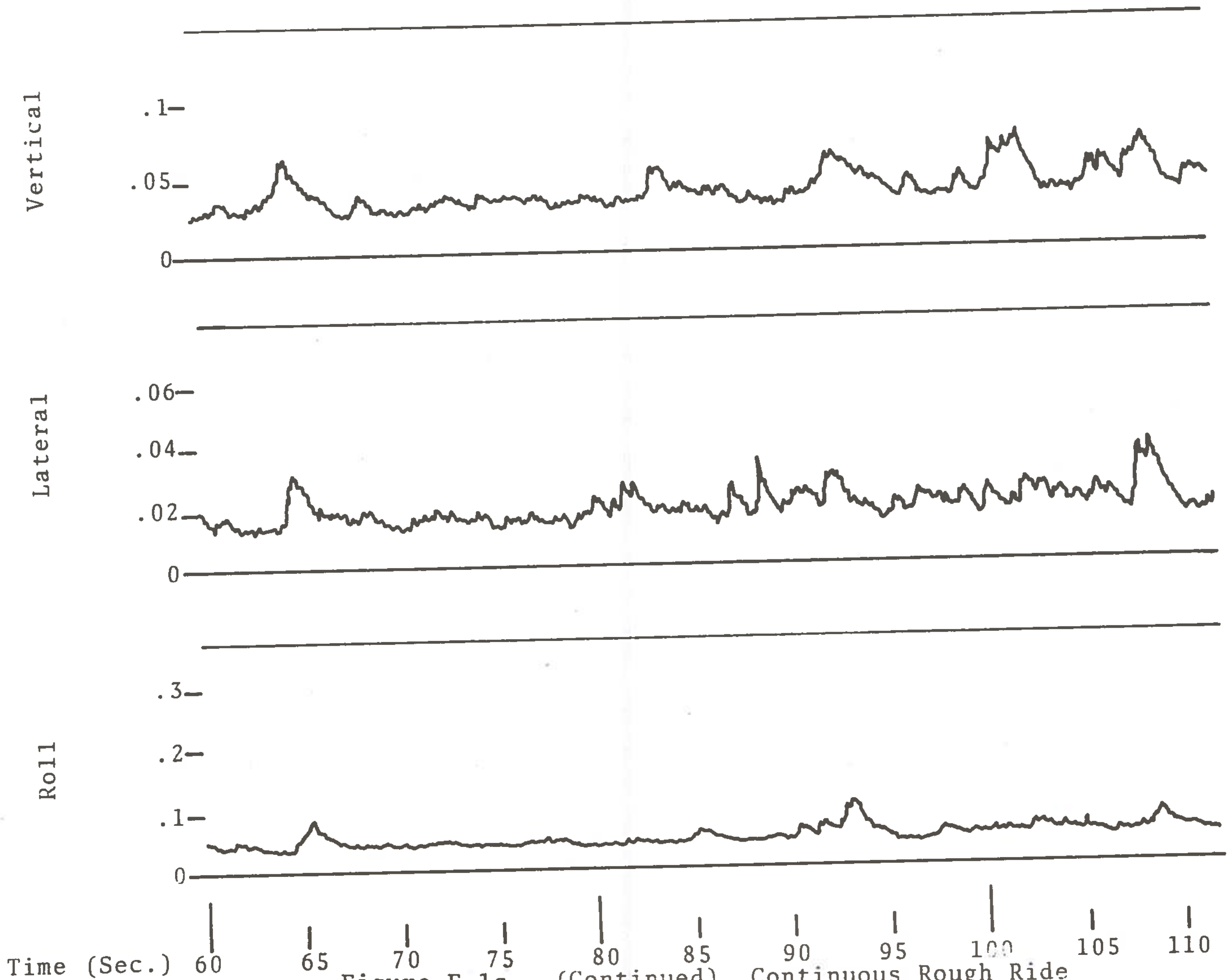


Figure E-1c. (Continued) Continuous Rough Ride

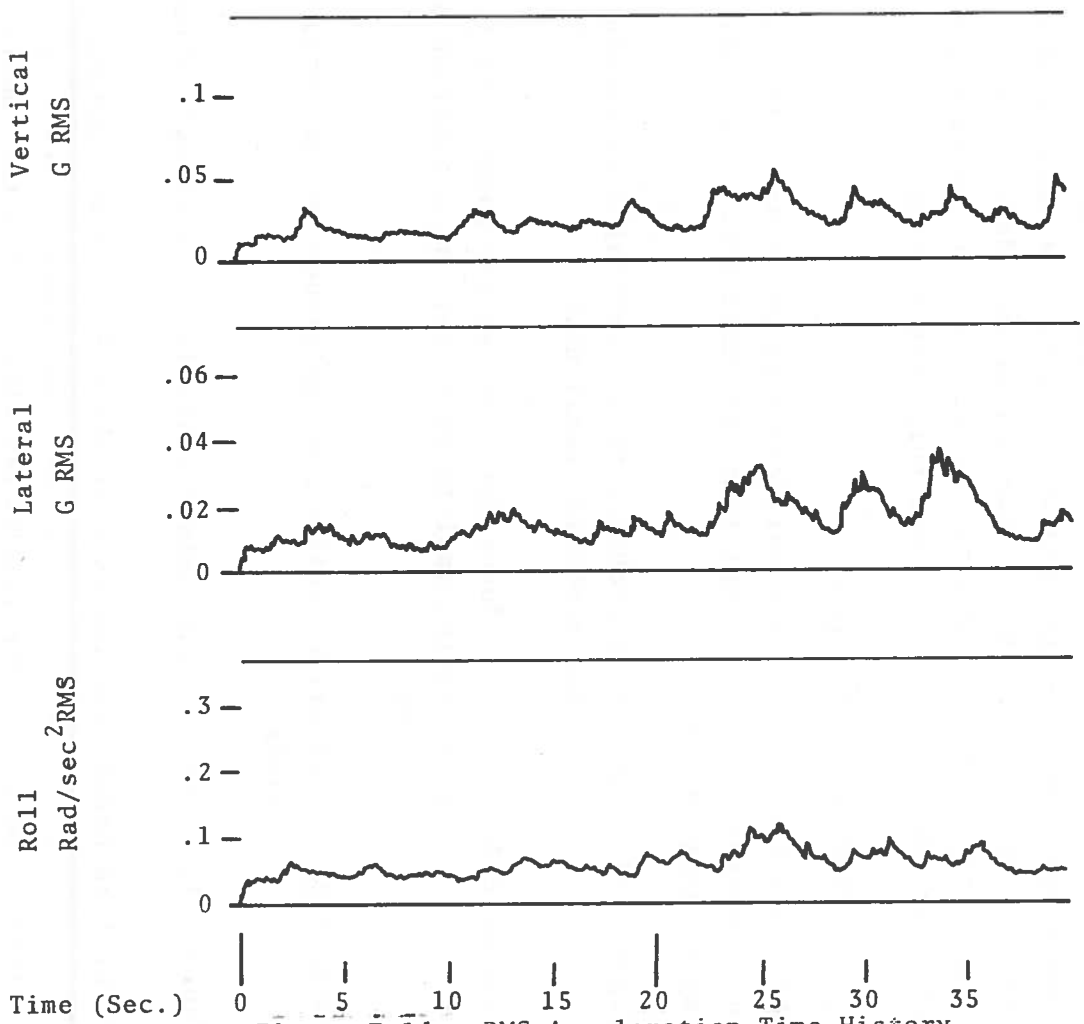


Figure E-1d. RMS Acceleration Time History
R3 - Roll Coupled Vibration Ride

E.4 ANALYSIS OF THE RIDE VIBRATION CHARACTERISTICS

The analog presentation of the vehicle vibrations provides a comprehensive record of the ride. This data must be reduced to parametric form to facilitate comparisons between rides and the analysis of the correlation of features of the ride and the perceived ride quality. For purposes of analysis at this stage, the important features are the differences between the ride segments. The following paragraphs describe and compare the four ride segments in terms of the characteristics of their vertical, lateral, and roll accelerations.

E.4.1 VERTICAL VIBRATIONS

The characteristics of the vertical accelerations of the four ride segments at normal amplitude are summarized in the following Figures and Tables.

Figure E-2.	Cumulative probability of vertical accelerations less than specified amplitudes.
Figures E-3a, b, c, d.	Power Spectral density plots: Vertical acceleration amplitudes (power) as a function of frequency.
Table E-2.	Vertical vibration rms amplitudes in ISO frequency bands.
Table E-3.	ISO reduced comfort criteria for vertical vibration.

It will be noted from analyses of these Figures and Tables that the vertical vibrations of all four ride segments are very similar. The continuous rough ride differs from the smooth ride in the relative amplitude of vertical motion at 1 1/2 to 2 hz, which corresponds to the bounce mode of the primary truck suspension.

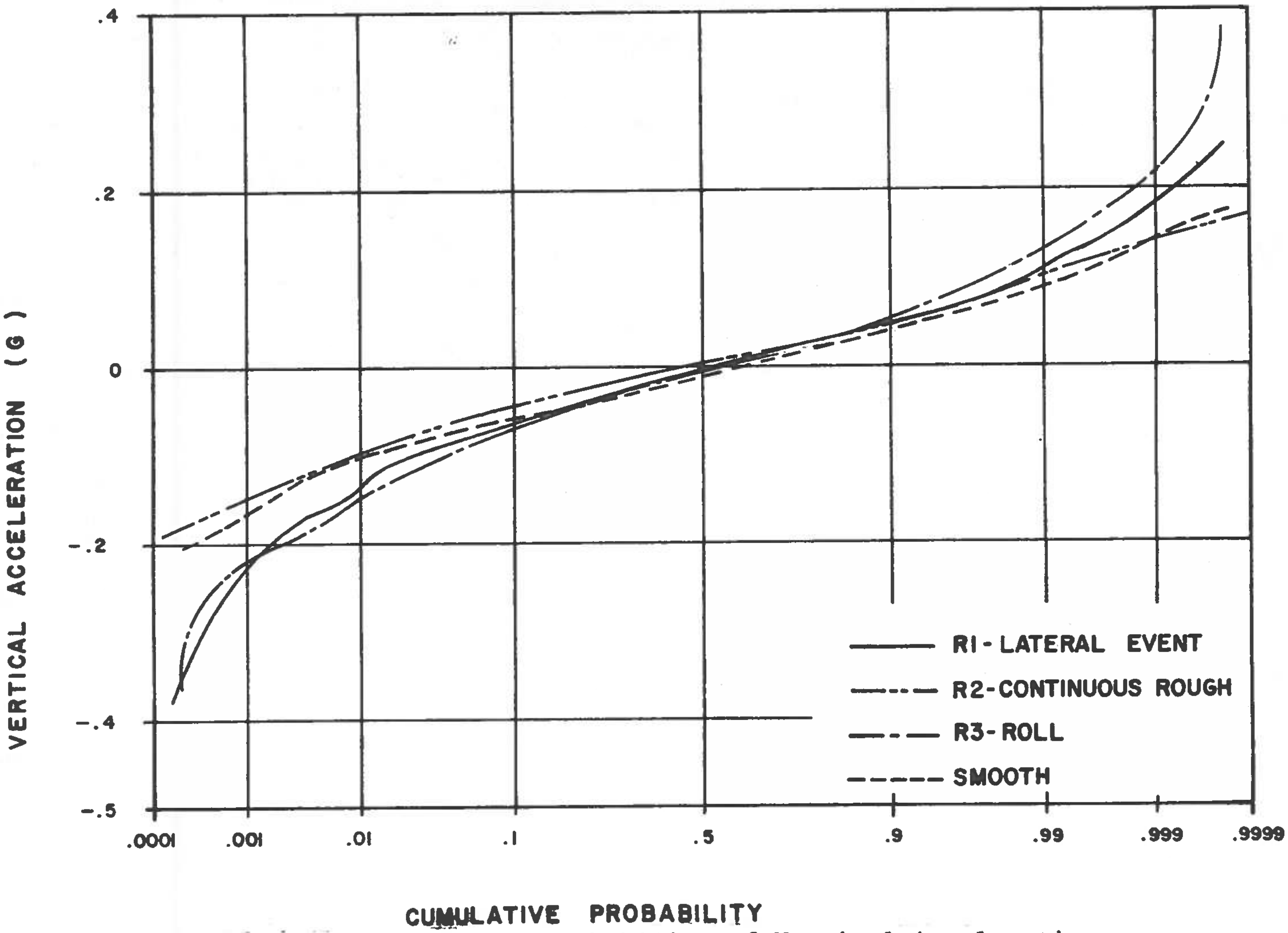


Figure E-2. Cumulative Probability of Vertical Accelerations

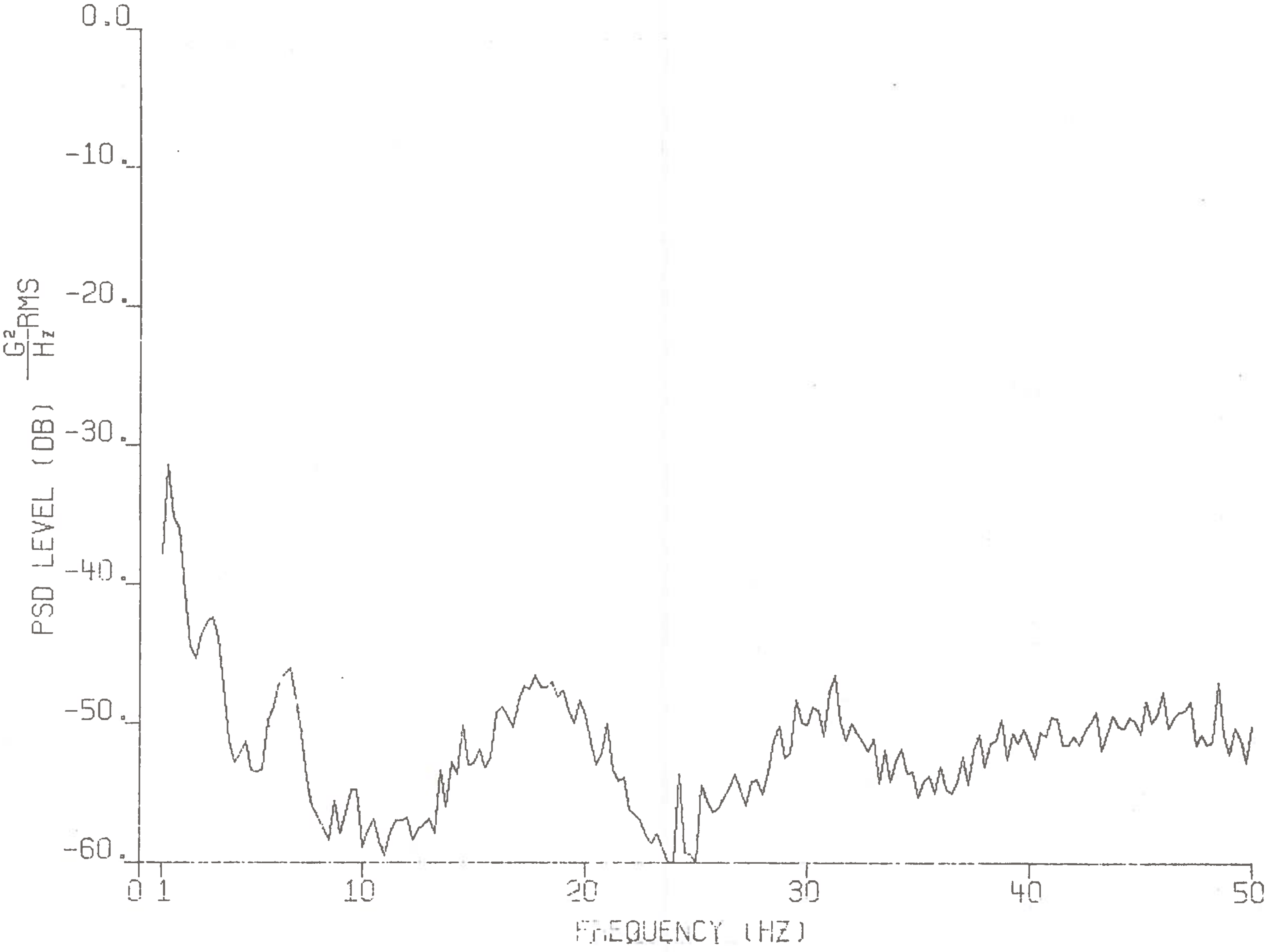


Figure E-3a.

Power Spectral Density of Vertical Accelerations

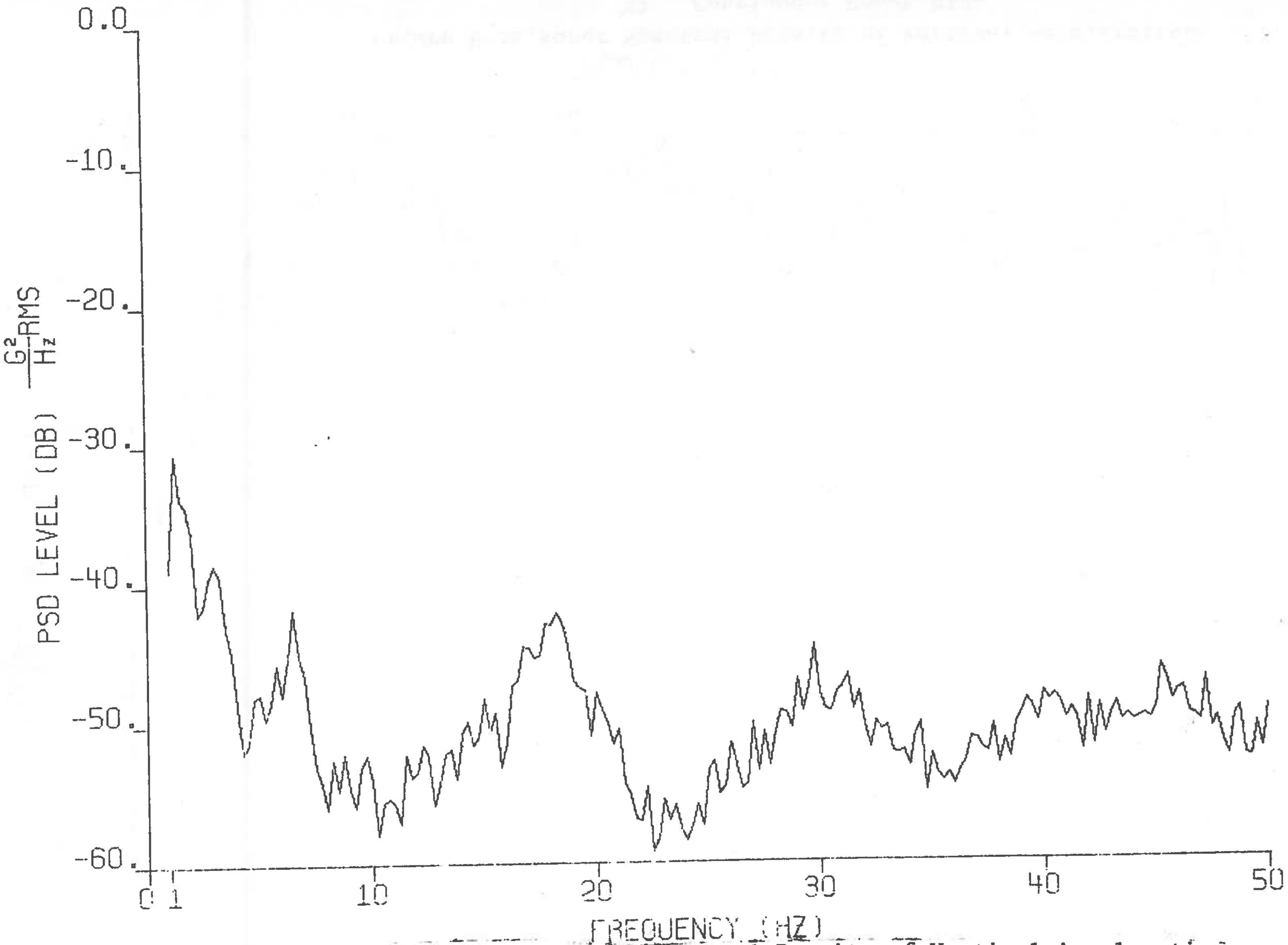


Figure E-3b. Power Spectral Density of Vertical Accelerations
R1 - Lateral Event Ride

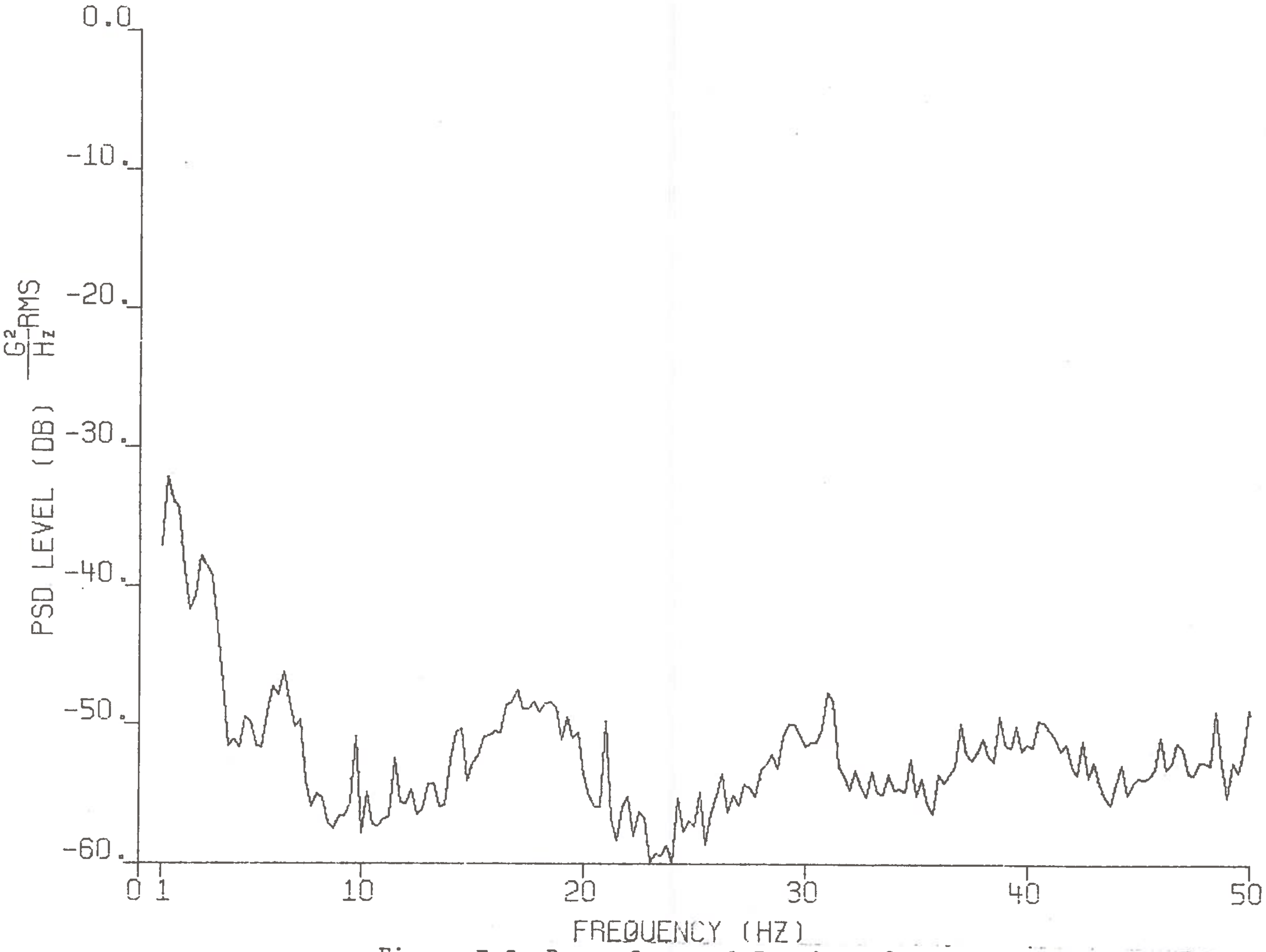


Figure E-3c. Power Spectral Density of Vertical Accelerations

R2 - Continuous Rough Ride

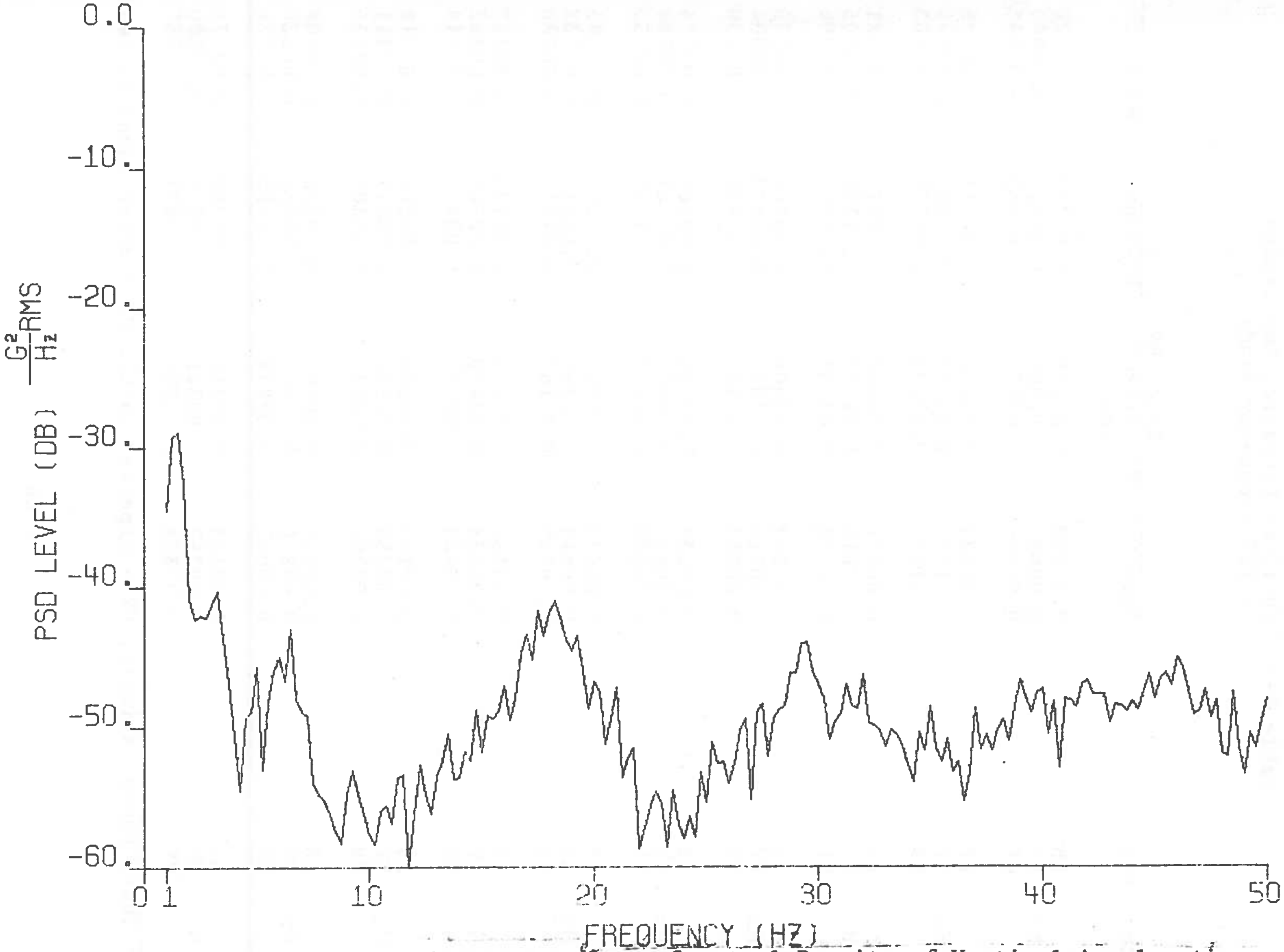


Figure E-3d. Power Spectral Density of Vertical Accelerations
R3 - Roll Coupled Vibration Ride

Table E-2. Vertical Vibration Amplitudes in ISO Frequency Bands

Center Freq		Ride--RMS in G's			
		Smooth	R1-Lateral Event	R2-Rough	R3-Roll
	LB	0.00000	0.00108	0.00210	0.00490
1.0 Hz	EV	0.00643	0.00569	0.00697	0.00945
	UB	0.00994	0.00797	0.00963	0.01243
	LB	0.00524	0.00000	0.00516	0.00248
1.3 Hz	EV	0.01392	0.01523	0.01295	0.01870
	UB	0.01897	0.02302	0.01758	0.02633
	LB	0.00421	0.00000	0.00111	0.01381
1.6 Hz	EV	0.01015	0.01202	0.01196	0.01895
	UB	0.01373	0.01731	0.01687	0.02296
	LB	0.00392	0.00000	0.00000	0.00579
2.0 Hz	EV	0.00716	0.01021	0.00877	0.00904
	UB	0.00933	0.01467	0.01430	0.01139
	LB	0.00238	0.00518	0.00000	0.00374
2.5 Hz	EV	0.00457	0.00687	0.00785	0.00594
	UB	0.00600	0.00822	0.01115	0.00753
	LB	0.00429	0.00504	0.00000	0.00545
3.1 Hz	EV	0.00614	0.00896	0.00917	0.00732
	UB	0.00755	0.01162	0.01341	0.00880
	LB	0.00150	0.00311	0.00183	0.00227
4.0 Hz	EV	0.00338	0.00420	0.00360	0.00352
	UB	0.00454	0.00505	0.00476	0.00444
	LB	0.00185	0.00146	0.00184	0.00218
5.0 Hz	EV	0.00250	0.00396	0.00314	0.00411
	UB	0.00302	0.00540	0.00405	0.00539
	LB	0.00356	0.00467	0.00336	0.00408
6.3 Hz	EV	0.00510	0.00685	0.00482	0.00620
	UB	0.00627	0.00848	0.00593	0.00776
	LB	0.00164	0.00250	0.00200	0.00170
8.0 Hz	EV	0.00257	0.00321	0.00271	0.00280
	UB	0.00324	0.00380	0.00327	0.00357

LB = lower bound estimate; EV = expected value; UB = upper bound estimate

Table E-2. (Continued)

Center Freq		Ride--RMS in G's			
		Smooth	R1-Lateral Event	R2-Rough	R3-Roll
10.0 Hz	LB	0.00179	0.00205	0.00211	0.00203
	EV	0.00215	0.00280	0.00258	0.00253
	UB	0.00246	0.00339	0.00297	0.00295
12.5 Hz	LB	0.00179	0.00205	0.00211	0.00203
	EV	0.00265	0.00390	0.00311	0.00351
	UB	0.00308	0.00457	0.00358	0.00440
16.0 Hz	LB	0.00476	0.00384	0.00433	0.00235
	EV	0.00618	0.00831	0.00610	0.00898
	UB	0.00732	0.0111	0.00746	0.01248
20.0 Hz	LB	0.00530	0.00487	0.00333	0.00451
	EV	0.00691	0.00934	0.00567	0.01094
	UB	0.00822	0.01227	0.00729	0.01479
25.0 Hz	LB	0.00328	0.00346	0.00291	0.00363
	EV	0.00376	0.00485	0.00377	0.00569
	UB	0.00419	0.00593	0.00447	0.00719
31.5 Hz	LB	0.00616	0.00679	0.00518	0.00551
	EV	0.00777	0.00922	0.00665	0.01030
	UB	0.00910	0.01113	0.00785	0.01349
40.0 Hz	LB	0.00696	0.00782	0.00591	0.00760
	EV	0.00831	0.00929	0.00751	0.01075
	UB	0.00947	0.01056	0.00883	0.01317
50.0 Hz	LB	0.00656	0.00836	0.00294	0.00806
	EV	0.01057	0.01061	0.01108	0.01303
	UB	0.01343	0.01246	0.01539	0.01657
63.0 Hz	LB	0.01567	0.01534	0.01440	0.01540
	EV	0.01805	0.02104	0.01625	0.02081
	UB	0.02015	0.02549	0.01790	0.02508
80.0 Hz	LB	0.01501	0.01318	0.01183	0.01333
	EV	0.01854	0.02263	0.01433	0.02313
	UB	0.02150	0.02916	0.01646	0.02987

LB = lower bound estimate; EV = expected value; UB = upper bound estimate.

Table E-3. ISO Reduced Comfort Criteria for Vertical Vibration Reduced Comfort Limits in Hours

Reduced Comfort Exposure Limits	Ride			
	Smooth	R1-Lateral Event	R2-Rough	R3-Roll
Frequency--Hz	1.3	1.3	3.1	1.6
Hours	9.72	8.69	9.21	5.71

Center Freq		Smooth	R1	R2	R3
1.0 Hz	LB	24.00	24.00	24.00	24.00
	EV	24.00	24.00	24.00	17.88
	UB	16.81	21.90	17.47	12.84
1.3 Hz	LB	24.00	24.00	24.00	24.00
	EV	9.72	8.69	10.61	6.72
	UB	6.60	5.15	7.27	4.32
1.6 Hz	LB	24.00	24.00	24.00	8.51
	EV	12.42	10.10	10.17	5.71
	UB	8.57	6.41	6.62	4.45
2.0 Hz	LB	24.00	24.00	24.00	21.25
	EV	16.48	10.71	12.89	12.44
	UB	11.96	6.83	7.06	9.36
2.5 Hz	LB	24.00	21.14	24.00	24.00
	EV	24.00	15.07	12.83	17.94
	UB	17.73	12.13	8.33	13.48
3.1 Hz	LB	23.07	19.06	24.00	17.34
	EV	15.03	9.48	9.21	12.14
	UB	11.70	6.85	5.71	9.69
4.0 Hz	LB	24.00	24.00	24.00	24.00
	EV	24.00	20.66	24.00	24.00
	UB	18.79	16.54	17.78	19.32
5.0 Hz	LB	24.00	24.00	24.00	24.00
	EV	24.00	22.15	24.00	21.17
	UB	24.00	15.25	21.57	15.30
6.3 Hz	LB	24.00	18.16	24.00	21.36
	EV	16.37	11.44	17.50	12.92
	UB	12.75	8.80	13.63	9.82
8.0 Hz	LB	24.00	24.00	24.00	24.00
	EV	24.00	24.00	24.00	24.00
	UB	24.00	23.29	24.00	24.00

Table E-3. (Continued)

Reduced Comfort Exposure Limits		Ride			
		Smooth	R1-Lateral Event	R2-Rough	R3-Roll
10.0 Hz	LB	24.00	24.00	24.00	24.00
	EV	24.00	24.00	24.00	24.00
	UB	24.00	24.00	24.00	24.00
12.5 Hz	LB	24.00	24.00	24.00	24.00
	EV	24.00	24.00	24.00	24.00
	UB	24.00	24.00	24.00	24.00
16.0 Hz	LB	24.00	24.00	24.00	24.00
	EV	24.00	20.83	24.00	19.01
	UB	24.00	14.71	23.72	12.78
20.0 Hz	LB	24.00	24.00	24.00	24.00
	EV	24.00	23.87	24.00	19.77
	UB	24.00	17.22	24.00	13.75
25.0 Hz	LB	24.00	24.00	24.00	24.00
	EV	24.00	24.00	24.00	24.00
	UB	24.00	24.00	24.00	24.00
31.5	LB	24.00	24.00	24.00	24.00
	EV	24.00	24.00	24.00	24.00
	UB	24.00	24.00	24.00	24.00
40.0 Hz	LB	24.00	24.00	24.00	24.00
	EV	24.00	24.00	24.00	24.00
	UB	24.00	24.00	24.00	24.00
50.0 Hz	LB	24.00	24.00	24.00	24.00
	EV	24.00	24.00	24.00	24.00
	UB	24.00	24.00	24.00	24.00
63.0 Hz	LB	24.00	24.00	24.00	24.00
	EV	24.00	24.00	24.00	24.00
	UB	24.00	24.00	24.00	24.00
80.0 Hz	LB	24.00	24.00	24.00	24.00
	EV	24.00	24.00	24.00	24.00
	UB	24.00	24.00	24.00	24.00

E.4.2 LATERAL VIBRATIONS

The characteristics of the lateral accelerations of the four ride segments at normal amplitude are summarized in the following Figures and Tables.

Figure E-4. Cumulative probability of lateral accelerations less than specified amplitudes.

Figures E-5a, b, c, d. Power Spectral Density plots: Lateral acceleration amplitudes (power) as a function of frequency.

Table E-4. Lateral vibration rms amplitudes in ISO frequency bands.

Table E-5. ISO reduced comfort criteria for lateral vibrations

The primary difference among the rides is the increased frequency of large amplitude lateral vibrations in the 'lateral event' and 'roll' rides.

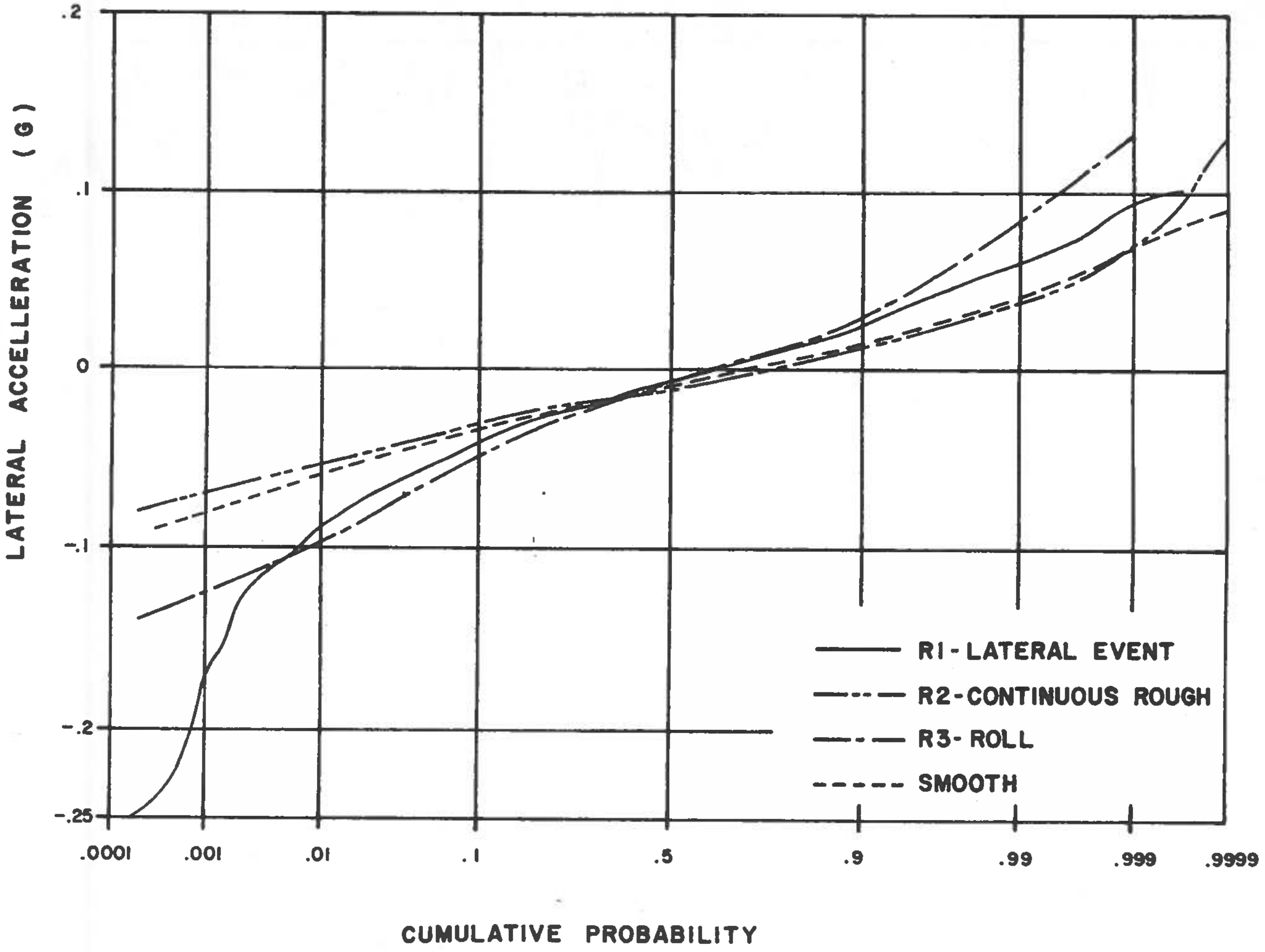


Figure E-4. Cumulative Probability of Lateral Accelerations

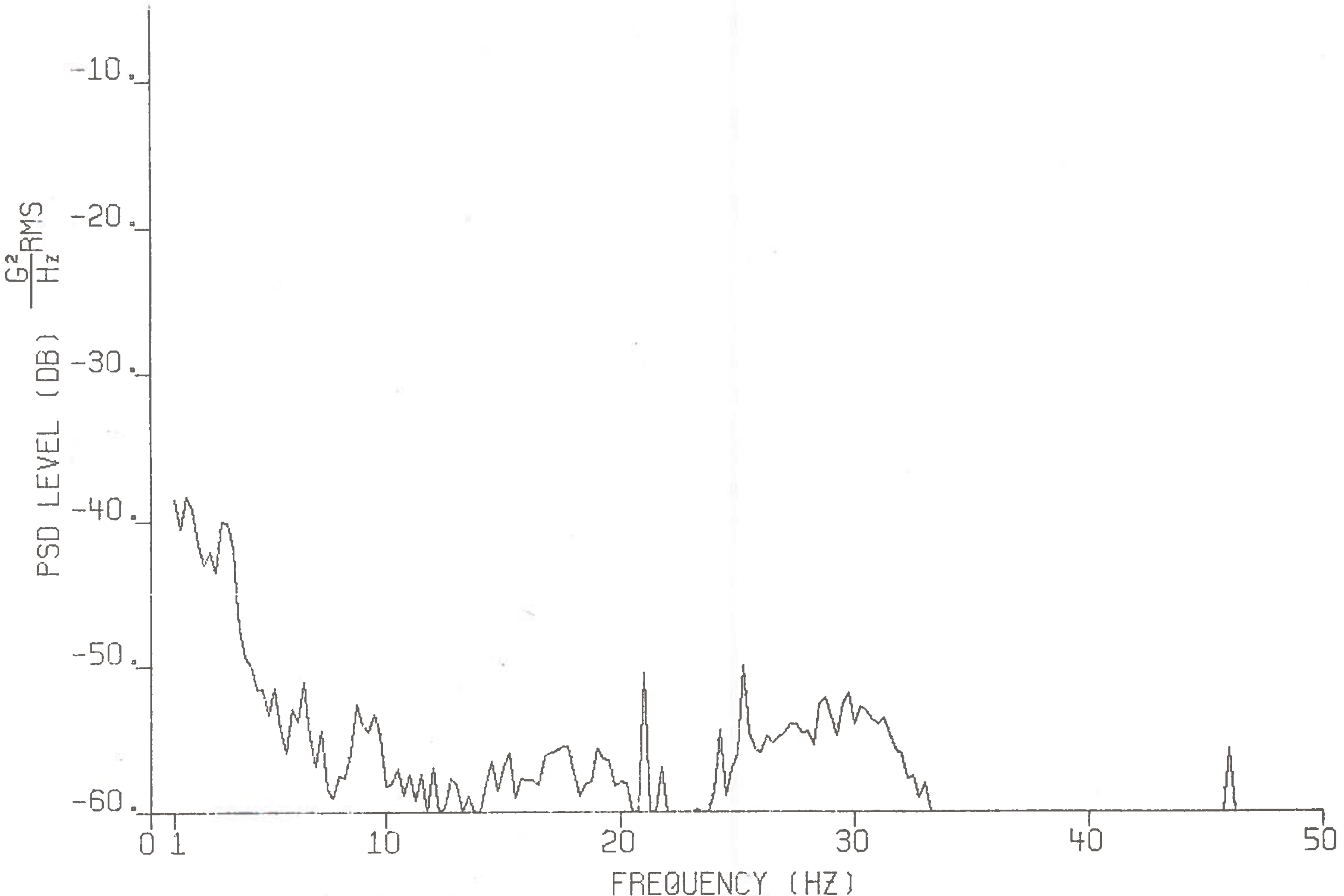


Figure E-5a.

Power Spectral Density of Lateral Accelerations

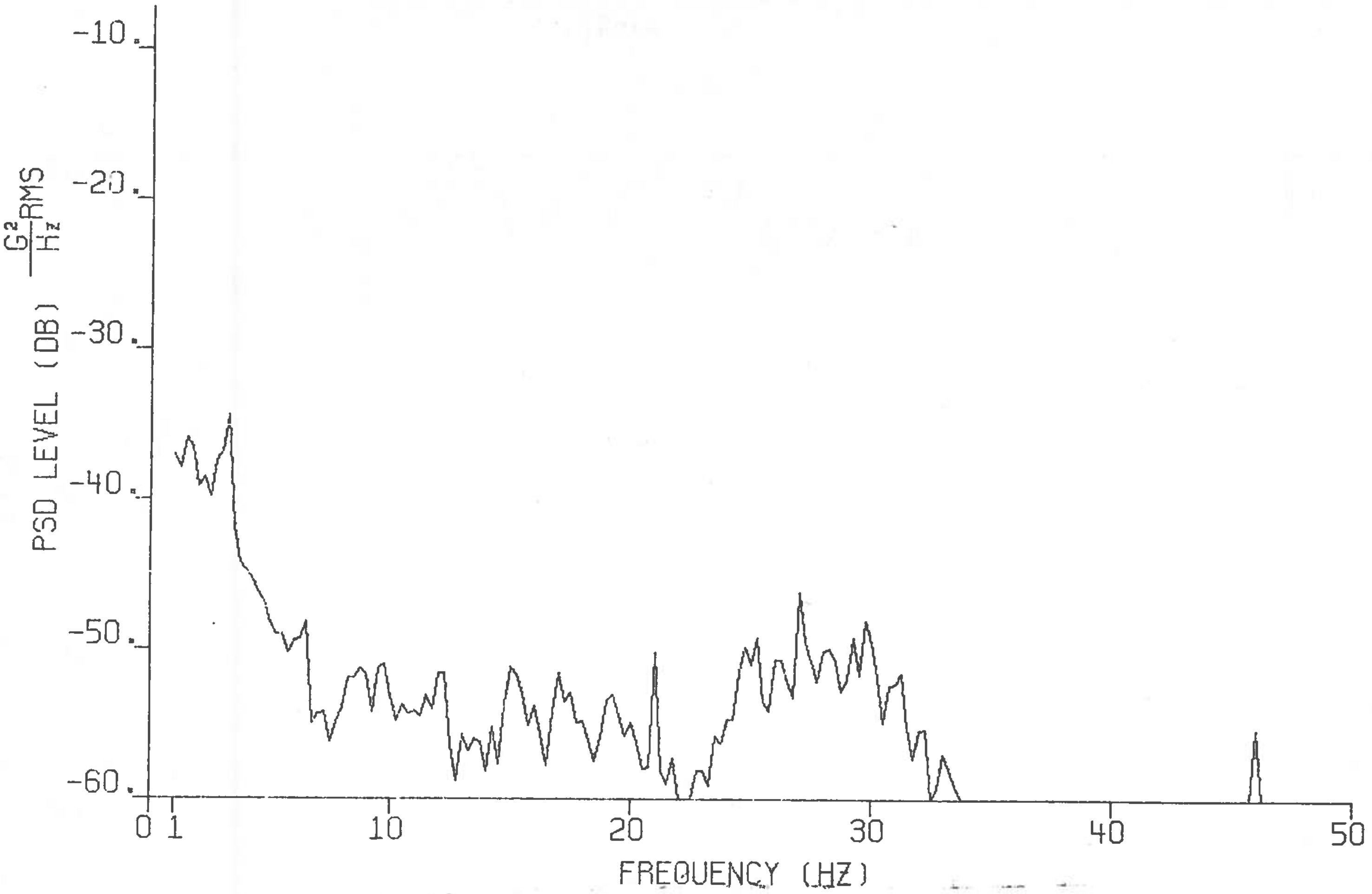


Figure E-5b.

Power Spectral Density of Lateral Accelerations

R1 - Lateral Event Ride

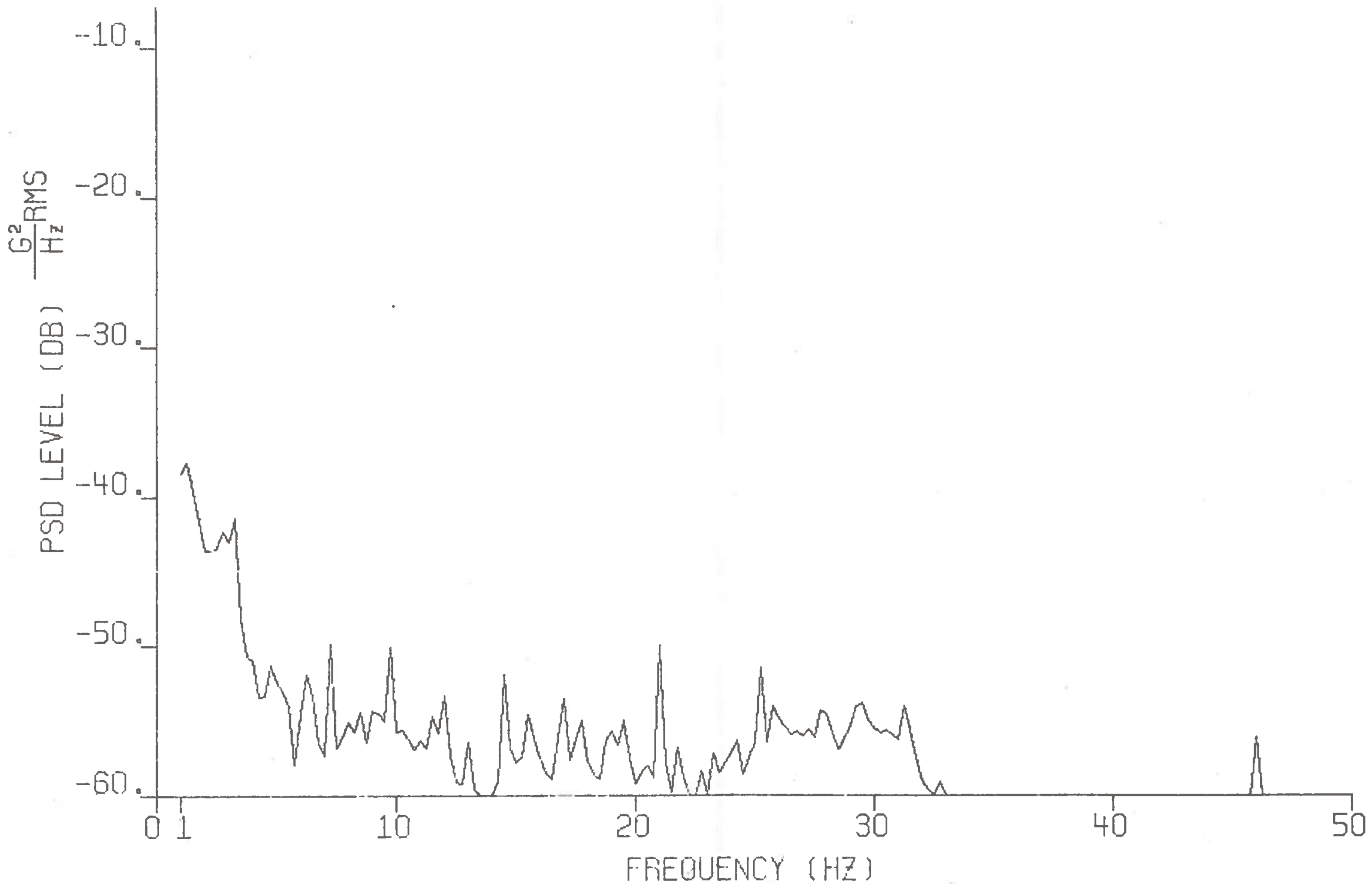


Figure E-5c.

Power Spectral Density of Lateral Accelerations

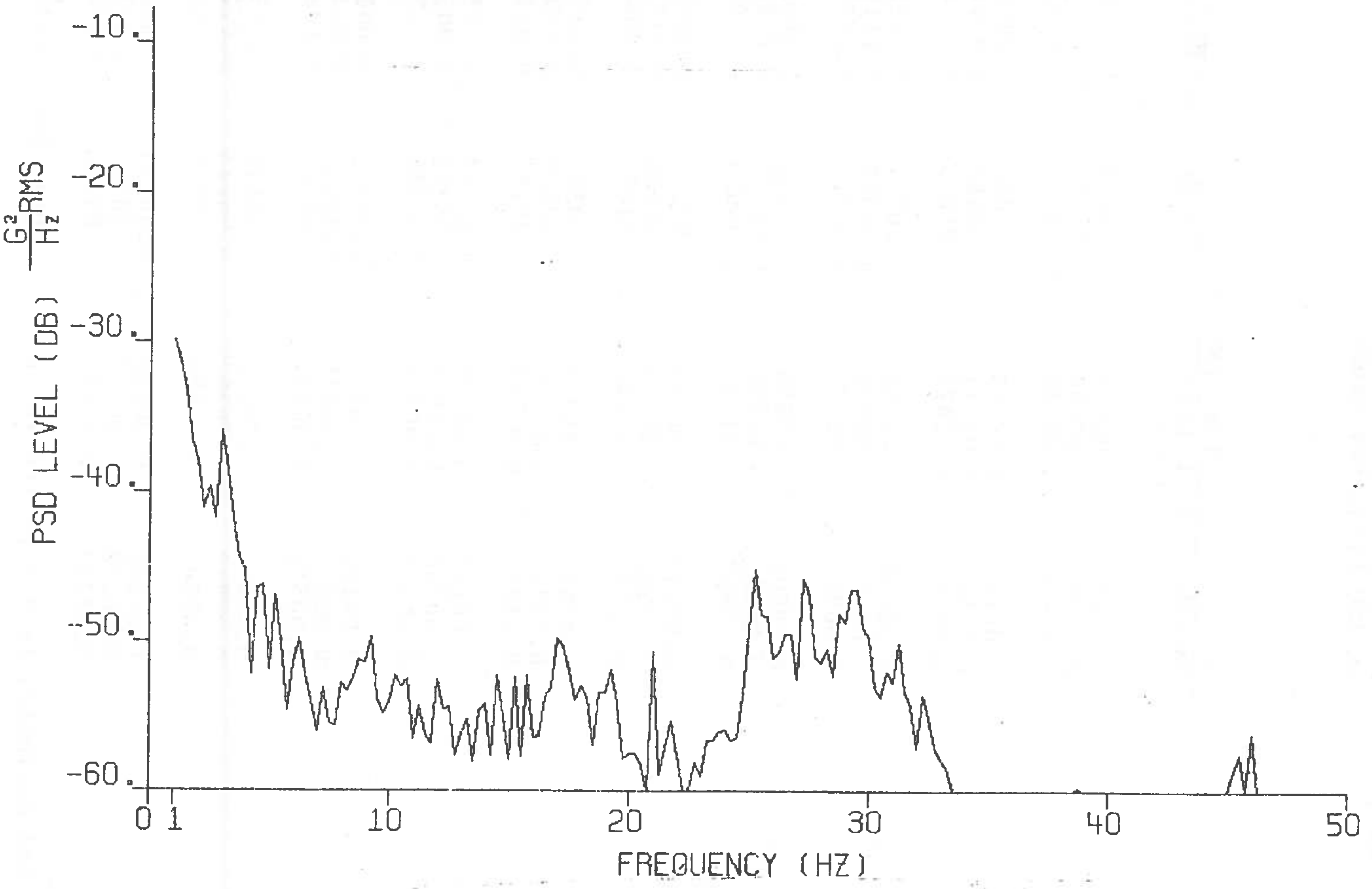


Figure E-5d.

Power Spectral Density of Lateral Accelerations
R3 - Roll Coupled Vibration Ride

Table E-4. Lateral Vibration Amplitudes in ISO Frequency Bands

Center Freq		Ride--RMS in G's			
		Smooth	R1-Lateral Event	R2-Rough	R3-Roll
1.0 Hz	LB	0.00000	0.00349	0.00235	0.00000
	EV	0.00596	0.00709	0.00601	0.01598
	UB	0.00876	0.00940	0.00816	0.02412
1.3 Hz	LB	0.00194	0.00235	0.00000	0.00000
	EV	0.00525	0.00711	0.00680	0.01423
	UB	0.00717	0.00977	0.01013	0.02225
1.6 Hz	LB	0.00000	0.00490	0.00281	0.00620
	EV	0.00701	0.00941	0.00582	0.01157
	UB	0.00994	0.01237	0.00773	0.01514
2.0 Hz	LB	0.00000	0.00559	0.00255	0.00587
	EV	0.00590	0.00830	0.00477	0.00842
	UB	0.00857	0.01033	0.00624	0.01036
2.5 Hz	LB	0.00240	0.00545	0.00291	0.00533
	EV	0.00552	0.00894	0.00536	0.00714
	UB	0.00743	0.01140	0.00698	0.00857
3.1 Hz	LB	0.00312	0.00477	0.00352	0.00736
	EV	0.00796	0.01292	0.00609	0.01074
	UB	0.01082	0.01763	0.00786	0.01329
4.0 Hz	LB	0.00142	0.00349	0.00154	0.00244
	EV	0.00392	0.00572	0.00261	0.00503
	UB	0.00536	0.00729	0.00336	0.00668
5.0 Hz	LB	0.00186	0.00290	0.00072	0.00000
	EV	0.00259	0.00436	0.00251	0.00435
	UB	0.00316	0.00545	0.00348	0.00643
6.3 Hz	LB	0.00170	0.00185	0.00149	0.00210
	EV	0.00248	0.00367	0.00223	0.00289
	UB	0.00307	0.00486	0.00279	0.00350
8.0 Hz	LB	0.00169	0.00130	0.00155	0.00220
	EV	0.00218	0.00298	0.00262	0.00298
	UB	0.00258	0.00401	0.00336	0.00359

LB = lower bound estimate; EV = expected value; UB = upper bound estimat

Table E-4. (Continued)

Center Freq		Ride--RMS in G's			
		Smooth	R1-Lateral Event	R2-Rough	R3-Roll
10.0 Hz	LB	0.00193	0.00274	0.00219	0.00268
	EV	0.00244	0.00340	0.00286	0.00348
	UB	0.00285	0.00395	0.00340	0.00413
12.5 Hz	LB	0.00164	0.00213	0.00179	0.00206
	EV	0.00192	0.00315	0.00236	0.00298
	UB	0.00217	0.00391	0.00282	0.00368
16.0 Hz	LB	0.00221	0.00278	0.00224	0.00276
	EV	0.00273	0.00395	0.00303	0.00413
	UB	0.00317	0.00484	0.00366	0.00515
20.0 Hz	LB	0.00254	0.00276	0.00201	0.00290
	EV	0.00298	0.00360	0.00316	0.00377
	UB	0.00336	0.00428	0.00399	0.00448
25.0 Hz	LB	0.00331	0.00258	0.00296	0.00360
	EV	0.00396	0.00619	0.00382	0.00713
	UB	0.00453	0.00836	0.00451	0.00942
31.5 Hz	LB	0.00372	0.00420	0.00256	0.00353
	EV	0.00448	0.00556	0.00361	0.00646
	UB	0.00513	0.00665	0.00441	0.00843
40.0 Hz	LB	0.00124	0.00125	0.00104	0.00143
	EV	0.00142	0.00167	0.00140	0.00174
	UB	0.00157	0.00201	0.00168	0.00200
50.0 Hz	LB	0.00154	0100151	0.00137	0.00174
	EV	0.00167	0.00172	0.00171	0.00197
	UB	0.00179	0.00190	0.00199	0.00217
63.0 Hz	LB	0.00556	0.00582	0.00578	0.00577
	EV	0.00570	0.00596	0.00594	0.00593
	UB	0.00584	0.00610	0.00610	0.00609
80.0	LB	0.00140	0.00128	0.00105	0.00141
	EV	0.00156	0.00172	0.00178	0.00170
	UB	0.00170	0.00206	0.00228	0.00195

LB = lower bound estimate; EV = expected value; UB = upper bound estimate.

Table E-5. ISO Reduced Comfort Criteria for Lateral Vibration--Reduced Comfort Limits in Hours

Reduced Comfort Exposure Limits		Ride			
		Smooth	R1-Lateral Event	R2-Rough	R3-Roll
Frequency--Hz		1.6	1.6	1.3	1.0
Hours		8.27	5.47	8.62	2.49
Center Freq		Smooth	R1	R2	R3
1.0 Hz	LB	24.00	21.30	24.00	24.00
	EV	10.35	8.14	10.23	2.49
	UB	6.05	5.48	6.69	1.25
1.3 Hz	LB	24.00	24.00	24.00	24.00
	EV	12.30	8.11	8.62	2.98
	UB	8.02	5.18	4.92	1.45
1.6 Hz	LB	24.00	13.50	24.00	9.80
	EV	8.27	5.47	10.69	4.06
	UB	5.06	3.68	7.21	2.71
2.0 Hz	LB	24.00	11.29	24.00	10.56
	EV	10.48	6.53	14.03	6.40
	UB	6.24	4.79	9.71	4.77
2.5 Hz	LB	24.00	15.97	24.00	16.45
	EV	15.71	8.13	16.39	11.08
	UB	10.49	5.78	11.42	8.62
3.1 Hz	LB	24.00	24.00	24.00	14.53
	EV	13.06	6.70	18.74	8.67
	UB	8.58	4.30	13.28	6.44
4.0 Hz	LB	24.00	24.00	24.00	24.00
	EV	24.00	24.00	24.00	24.00
	UB	24.00	20.05	24.00	22.58
5.0 Hz	LB	24.00	24.00	24.00	24.00
	EV	24.00	24.00	24.00	24.00
	UB	24.00	24.00	24.00	24.00
6.3 Hz	LB	24.00	24.00	24.00	24.00
	EV	24.00	24.00	24.00	24.00
	UB	24.00	24.00	24.00	24.00

Table E-5. (Continued)

Reduced Comfort Exposure Limits		Ride			
		Smooth	R1-Lateral Event	R2-Rough	R3-Roll
8.0 Hz	LB	24.00	24.00	24.00	24.00
	EV	24.00	24.00	24.00	24.00
	UB	24.00	24.00	24.00	24.00
10.0 Hz	LB	24.00	24.00	24.00	24.00
	EV	24.00	24.00	24.00	24.00
	UB	24.00	24.00	24.00	24.00
12.5 Hz	LB	24.00	24.00	24.00	24.00
	EV	24.00	24.00	24.00	24.00
	UB	24.00	24.00	24.00	24.00
16.0 Hz	LB	24.00	24.00	24.00	24.00
	EV	24.00	24.00	24.00	24.00
	UB	24.00	24.00	24.00	24.00
20.0 Hz	LB	24.00	24.00	24.00	24.00
	EV	24.00	24.00	24.00	24.00
	UB	24.00	24.00	24.00	24.00
25.0 Hz	LB	24.00	24.00	24.00	24.00
	EV	24.00	24.00	24.00	24.00
	UB	24.00	24.00	24.00	24.00
31.5 Hz	LB	24.00	24.00	24.00	24.00
	EV	24.00	24.00	24.00	24.00
	UB	24.00	24.00	24.00	24.00
40.0 Hz	LB	24.00	24.00	24.00	24.00
	EV	24.00	24.00	24.00	24.00
	UB	24.00	24.00	24.00	24.00
50.0 Hz	LB	24.00	24.00	24.00	24.00
	EV	24.00	24.00	24.00	24.00
	UB	24.00	24.00	24.00	24.00
63.0 Hz	LB	24.00	24.00	24.00	24.00
	EV	24.00	24.00	24.00	24.00
	UB	24,00	24.00	24.00	24.00
80.0 Hz	LB	24.00	24.00	24.00	24.00
	EV	24.00	24.00	24.00	24.00
	UB	24.00	24.00	24.00	24.00

E.4.3 ROLL

The characteristics of the roll (lateral rotational) accelerations of the four ride segments at normal amplitude are summarized in the following Figures and Tables:

Figure E-6. Cumulative probability of roll acceleration less than specified amplitudes.

Figure E-7a, b, c, d. Power spectral density plots: Roll Acceleration amplitudes (power) as a function of frequency.

The 'roll' ride is seen to have more power in the roll directio at about 1 hz, and a greater probability of extreme roll accelerations.

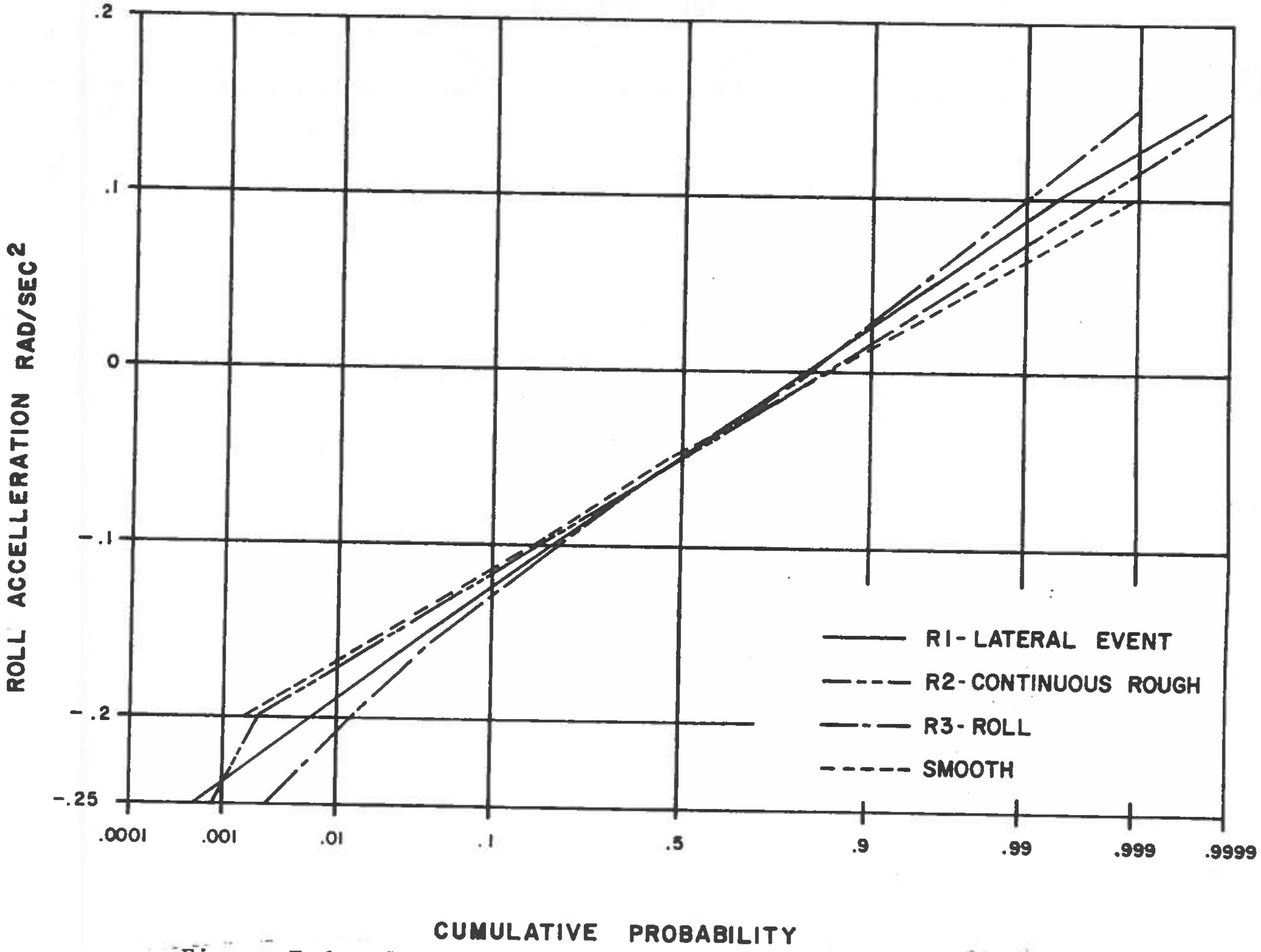


Figure E-6. Cumulative Probability of Roll Accelerations

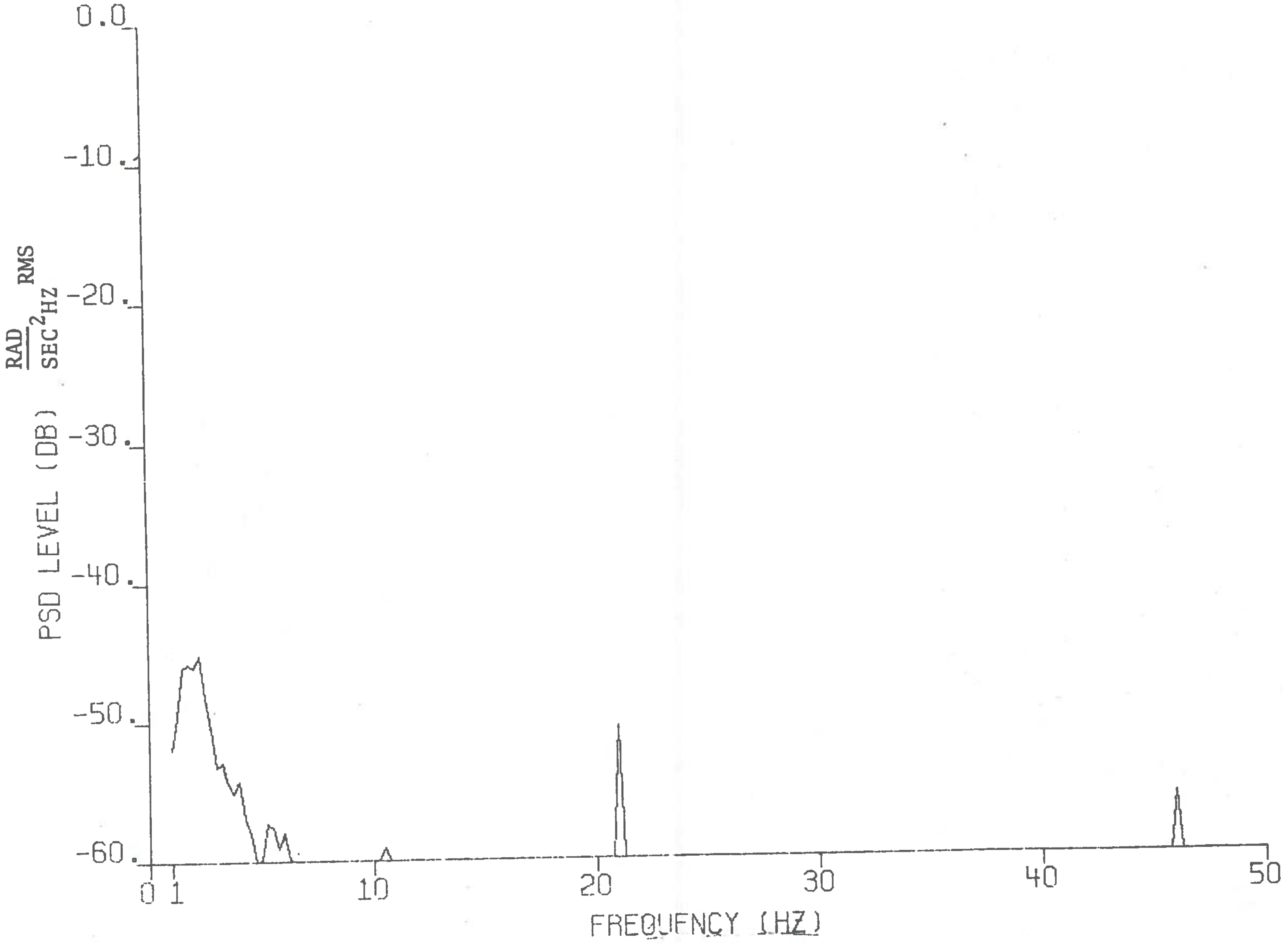


Figure E-7a.

Power Spectral Density of Roll Accelerations

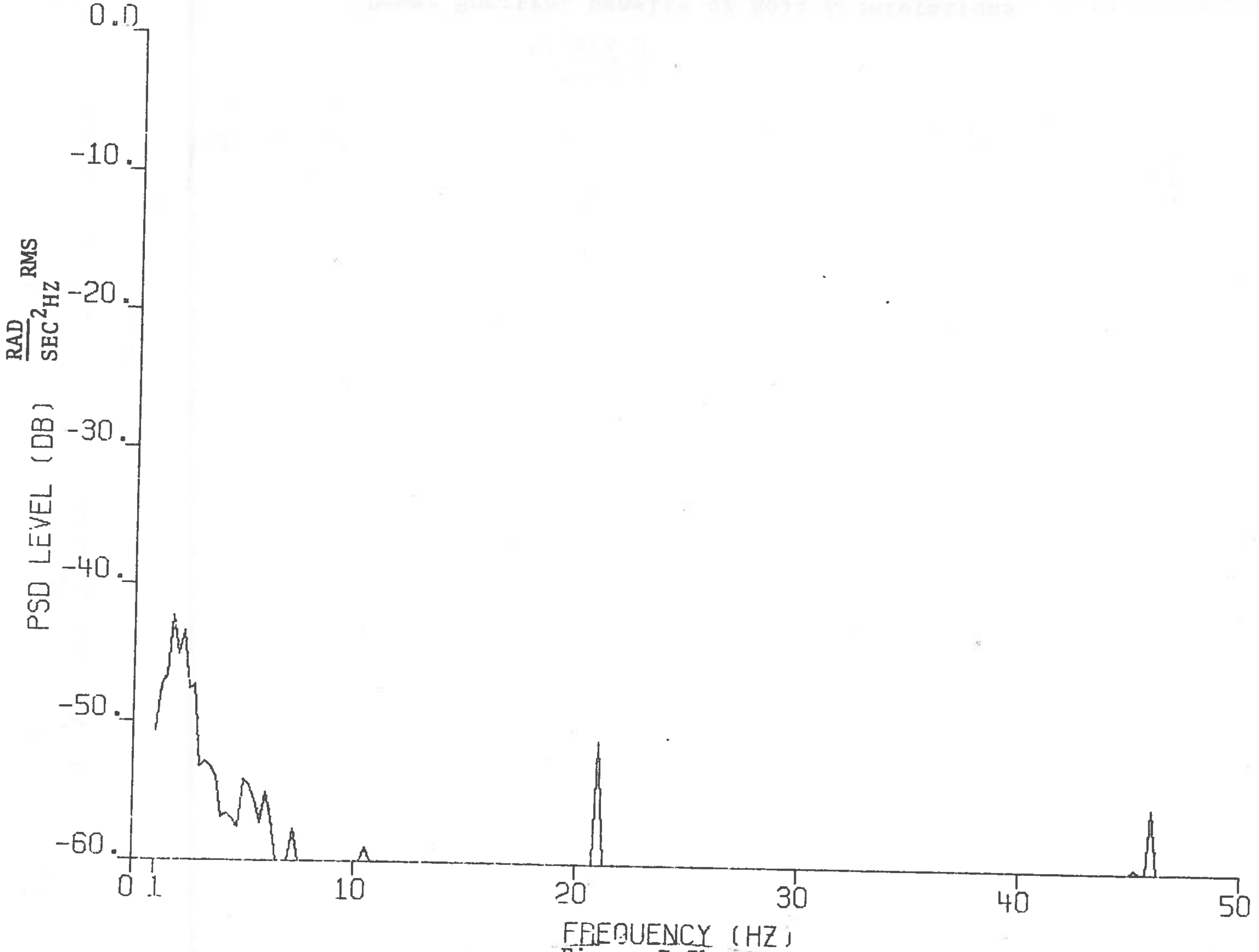


Figure E-7b.

Power Spectral Density of Roll Accelerations

R1 - Lateral Event Ride

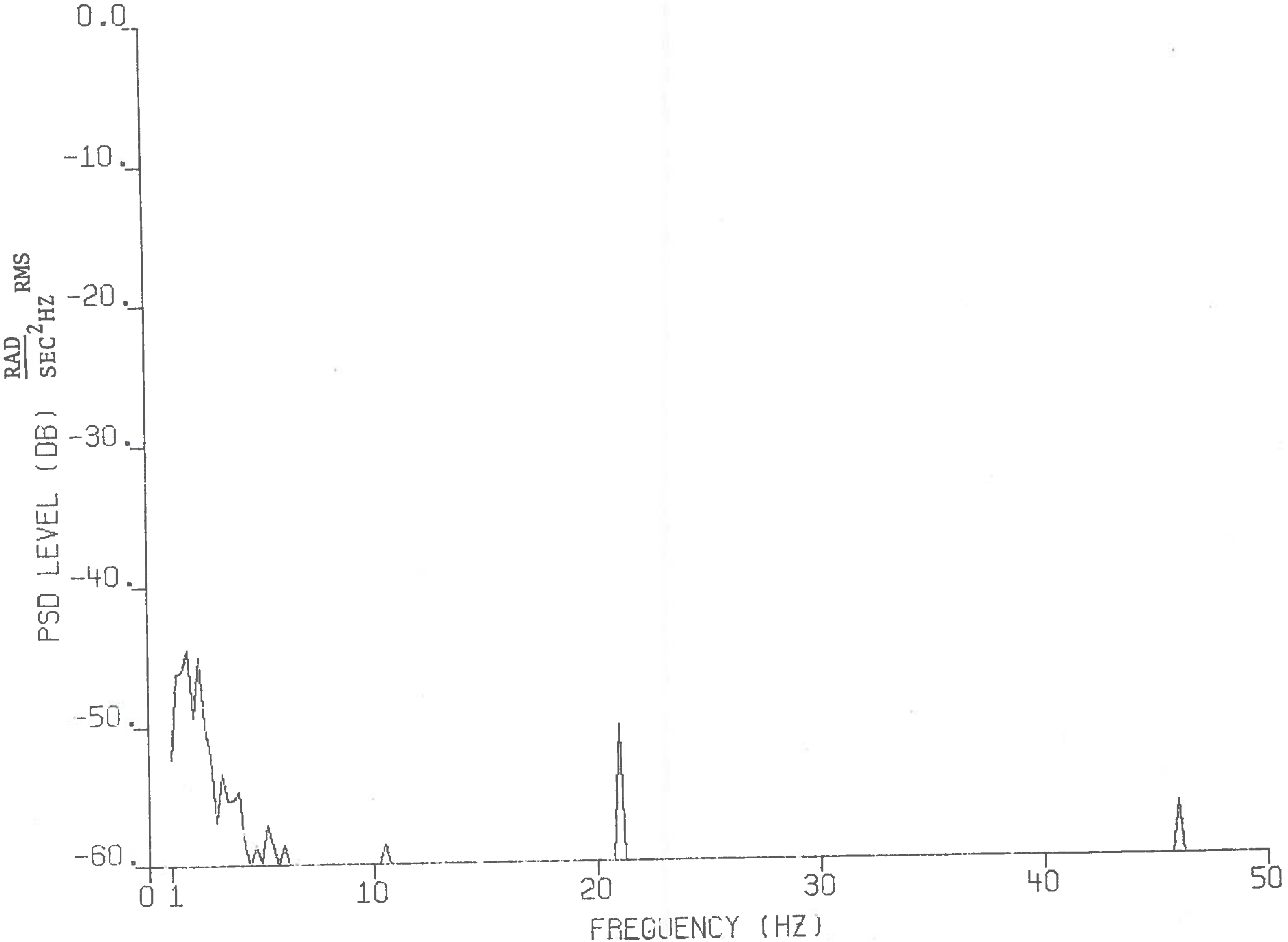


Figure E-7c.

Power Spectral Density of Roll Accelerations

R2 - Continuous Rough Ride

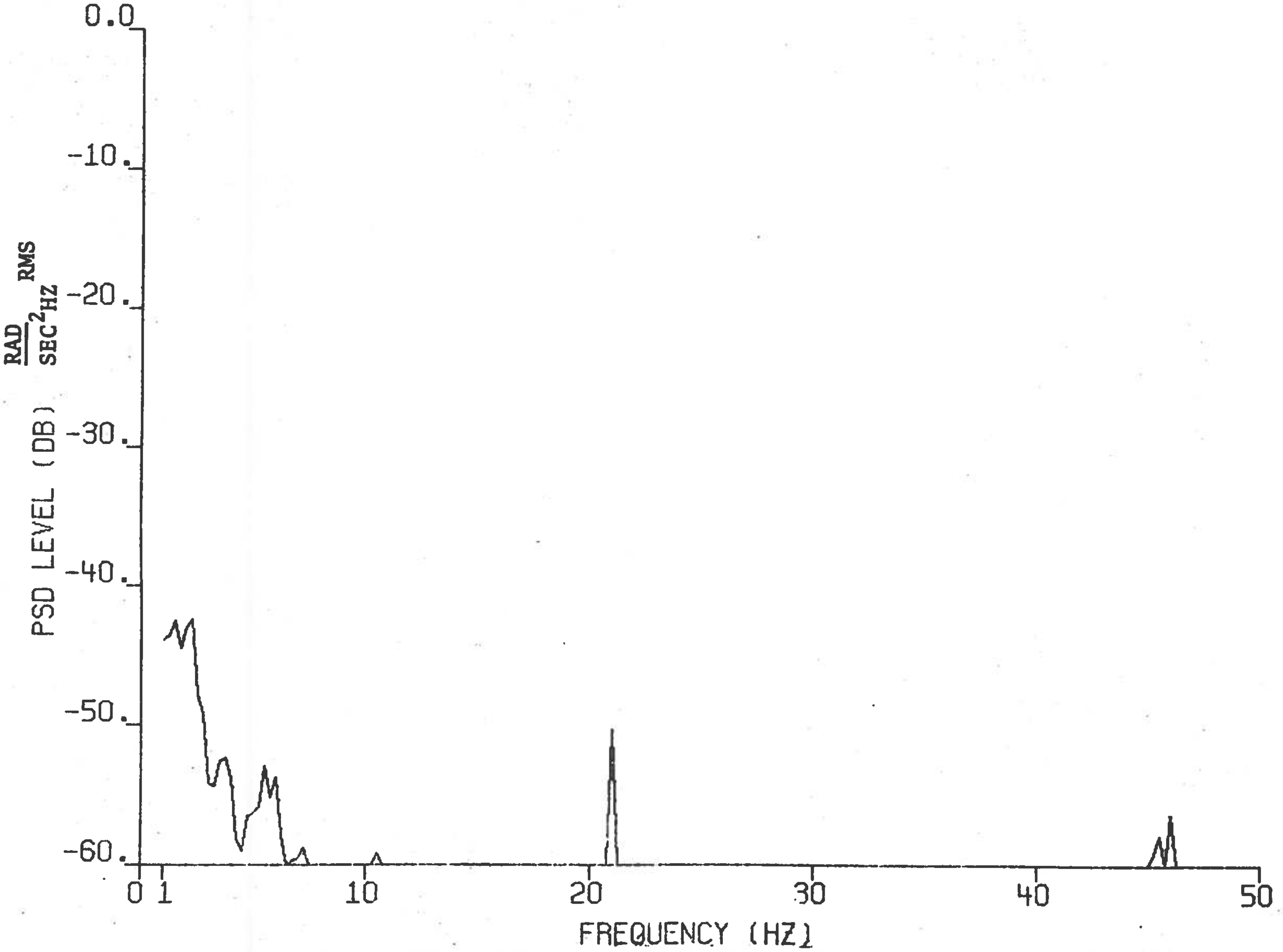


Figure E-7d. Power Spectral Density of Roll Accelerations
R3 - Roll Coupled Vibration Ride

APPENDIX F

QUESTIONNAIRES USED IN PSYCHOMETRIC SCALE DEVELOPMENT EXPERIMENTS

F.1 EXPERIMENT I

A booklet was given to each subject before each test run. This booklet contained a page of general instructions and the following questionnaire forms:

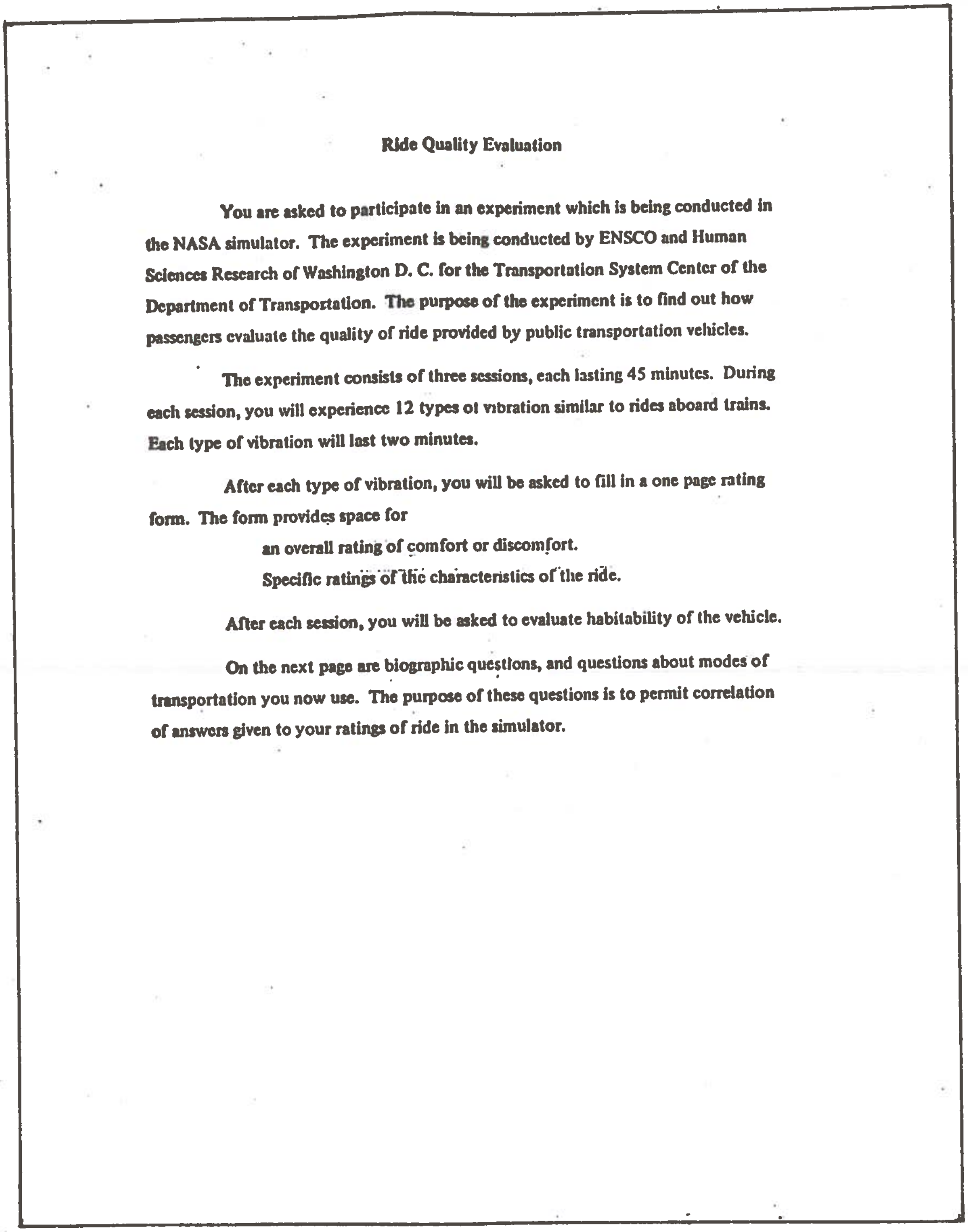
Demographic Data - three pages.

Ride Rating Scales - two pages per ride segment, 24 pages total. Order of the rating sheets was arranged to agree with ride presentation schedule.

Habitability Scales.

The booklets were printed on 8-1/2 x 11" paper, stapled in one corner, and clipped onto a stiff-backed clipboard. The subjects were asked to read the instructions, fill in the demographic data questionnaires, and become familiar with the ride rating scales before entering the simulator. The habitability scales were completed by the subjects after the test run, but before the subjects left the simulator.

The detailed format of the Experiment I questionnaire booklet is shown in Figure F-1.



Ride Quality Evaluation

You are asked to participate in an experiment which is being conducted in the NASA simulator. The experiment is being conducted by ENSCO and Human Sciences Research of Washington D. C. for the Transportation System Center of the Department of Transportation. The purpose of the experiment is to find out how passengers evaluate the quality of ride provided by public transportation vehicles.

The experiment consists of three sessions, each lasting 45 minutes. During each session, you will experience 12 types of vibration similar to rides aboard trains. Each type of vibration will last two minutes.

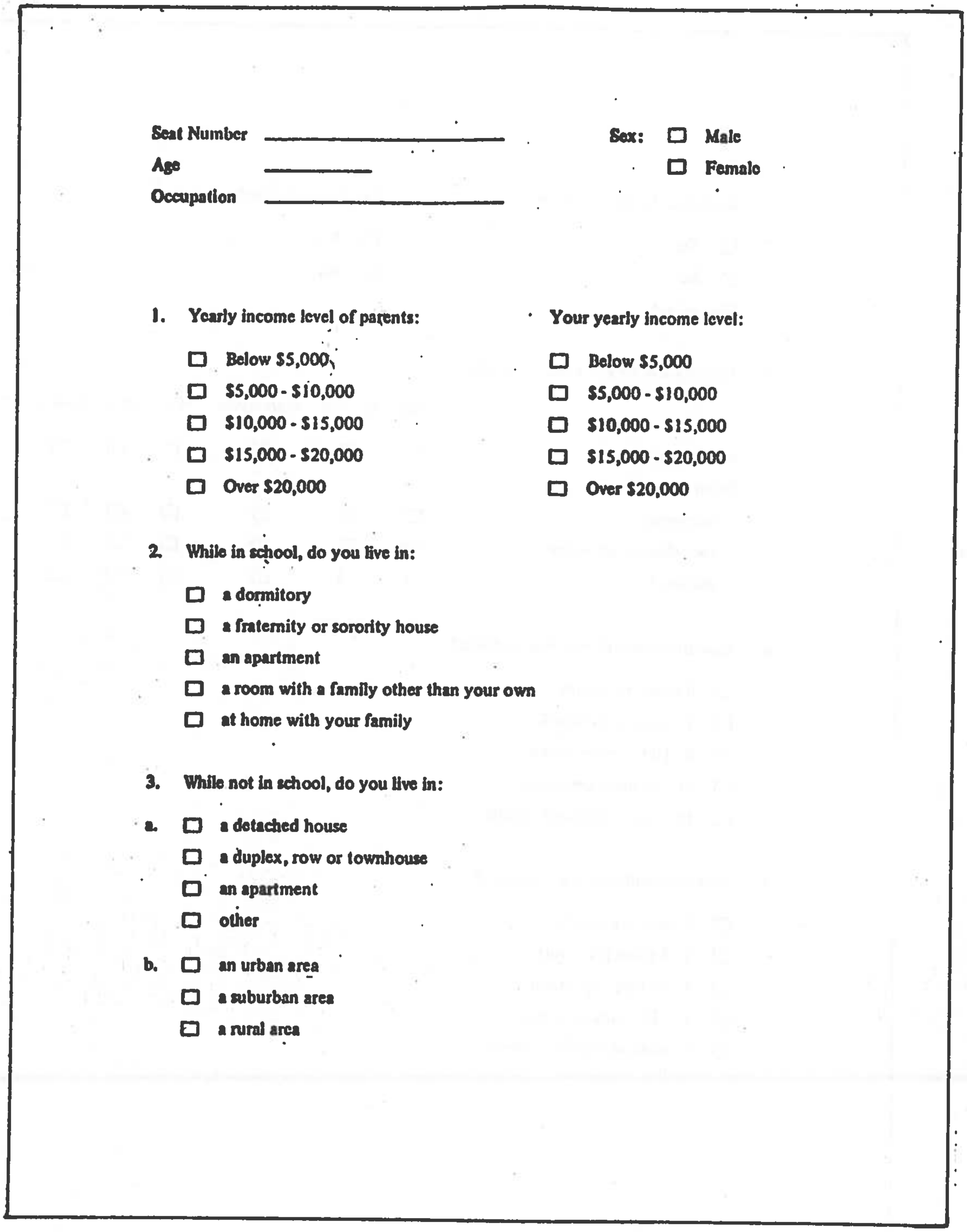
After each type of vibration, you will be asked to fill in a one page rating form. The form provides space for

an overall rating of comfort or discomfort.
Specific ratings of the characteristics of the ride.

After each session, you will be asked to evaluate habitability of the vehicle.

On the next page are biographic questions, and questions about modes of transportation you now use. The purpose of these questions is to permit correlation of answers given to your ratings of ride in the simulator.

Figure F-1a. Instructions for Experiment I



Seat Number ____________________ Sex: ☐ Male

Age __________ ☐ Female

Occupation ____________________

1. Yearly income level of parents:	Your yearly income level:
☐ Below $5,000	☐ Below $5,000
☐ $5,000 - $10,000	☐ $5,000 - $10,000
☐ $10,000 - $15,000	☐ $10,000 - $15,000
☐ $15,000 - $20,000	☐ $15,000 - $20,000
☐ Over $20,000	☐ Over $20,000

2. While in school, do you live in:

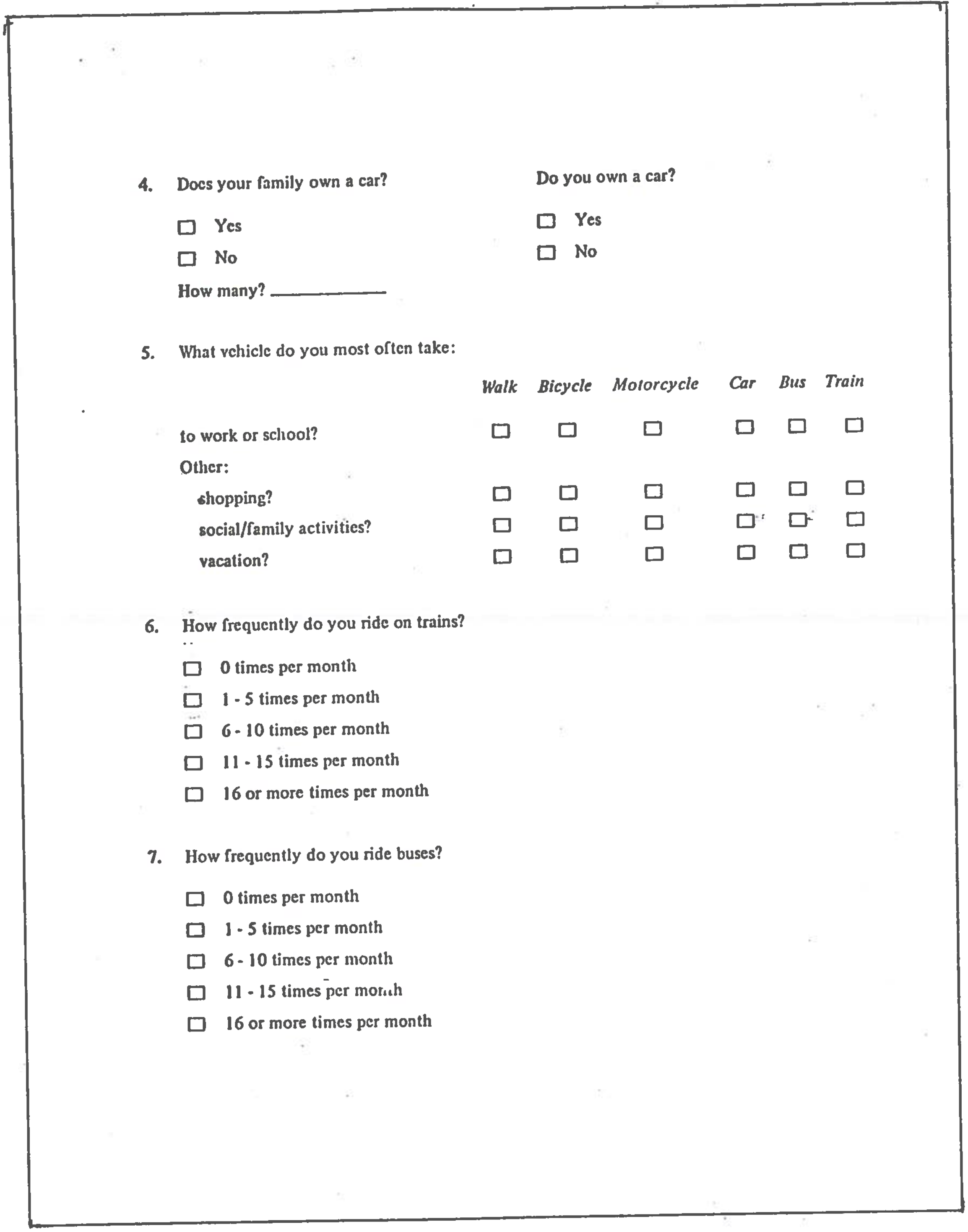
- ☐ a dormitory
- ☐ a fraternity or sorority house
- ☐ an apartment
- ☐ a room with a family other than your own
- ☐ at home with your family

3. While not in school, do you live in:

a. ☐ a detached house
   ☐ a duplex, row or townhouse
   ☐ an apartment
   ☐ other

b. ☐ an urban area
   ☐ a suburban area
   ☐ a rural area

Figure F-1b. Demographic Data Questionnaire, Page 1/3



4. Does your family own a car?

☐ Yes
☐ No
How many? ____________

Do you own a car?

☐ Yes
☐ No

5. What vehicle do you most often take:

	Walk	*Bicycle*	*Motorcycle*	*Car*	*Bus*	*Train*
to work or school?	☐	☐	☐	☐	☐	☐
Other:						
shopping?	☐	☐	☐	☐	☐	☐
social/family activities?	☐	☐	☐	☐	☐	☐
vacation?	☐	☐	☐	☐	☐	☐

6. How frequently do you ride on trains?

☐ 0 times per month
☐ 1 - 5 times per month
☐ 6 - 10 times per month
☐ 11 - 15 times per month
☐ 16 or more times per month

7. How frequently do you ride buses?

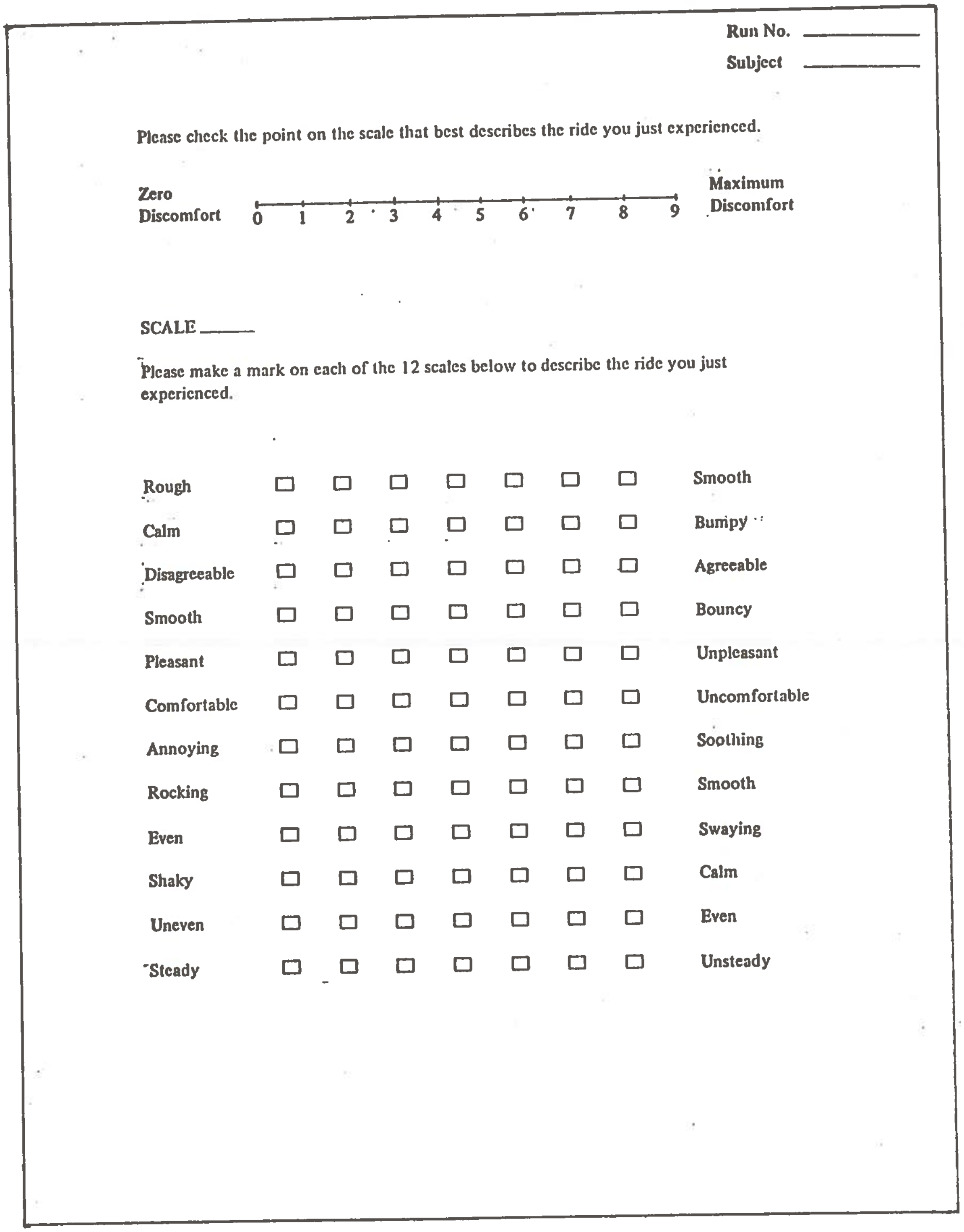
☐ 0 times per month
☐ 1 - 5 times per month
☐ 6 - 10 times per month
☐ 11 - 15 times per month
☐ 16 or more times per month

Figure F-1b (Cont.). Demographic Data Questionnaire, Page 2/3

8. How often do you drive or ride in a car?

- ☐ 0 times per month
- ☐ 1 - 5 times per month
- ☐ 6 - 10 times per month
- ☐ 11 - 15 times per month
- ☐ 16 - 20 times per month
- ☐ 21 or more times per month

Figure F-1b (Concl.). Demographic Data Questionnaire, Page 3/3



Run No. ____________

Subject ____________

Please check the point on the scale that best describes the ride you just experienced.

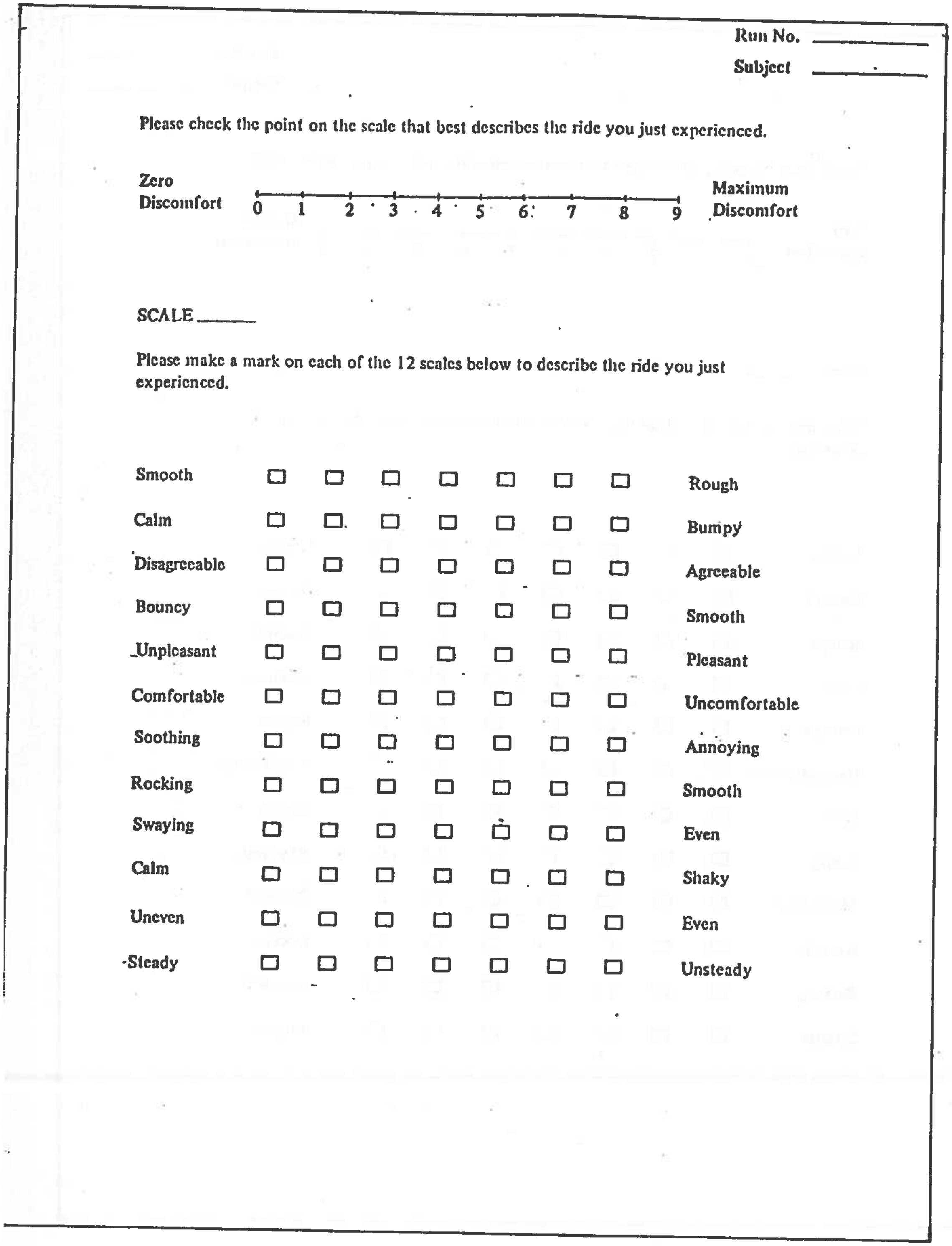
Zero Discomfort 0 1 2 3 4 5 6 7 8 9 Maximum Discomfort

SCALE ______

Please make a mark on each of the 12 scales below to describe the ride you just experienced.

Rough	☐	☐	☐	☐	☐	☐	☐	Smooth
Calm	☐	☐	☐	☐	☐	☐	☐	Bumpy
Disagreeable	☐	☐	☐	☐	☐	☐	☐	Agreeable
Smooth	☐	☐	☐	☐	☐	☐	☐	Bouncy
Pleasant	☐	☐	☐	☐	☐	☐	☐	Unpleasant
Comfortable	☐	☐	☐	☐	☐	☐	☐	Uncomfortable
Annoying	☐	☐	☐	☐	☐	☐	☐	Soothing
Rocking	☐	☐	☐	☐	☐	☐	☐	Smooth
Even	☐	☐	☐	☐	☐	☐	☐	Swaying
Shaky	☐	☐	☐	☐	☐	☐	☐	Calm
Uneven	☐	☐	☐	☐	☐	☐	☐	Even
Steady	☐	☐	☐	☐	☐	☐	☐	Unsteady

Figure F-1c. Ride Quality Questionnaire, Bi-polar Descriptive Scales for "Smooth Ride" Segments



Run No. ________

Subject ________

Please check the point on the scale that best describes the ride you just experienced.

Zero Discomfort 0 1 2 3 4 5 6 7 8 9 Maximum Discomfort

SCALE ______

Please make a mark on each of the 12 scales below to describe the ride you just experienced.

Smooth	☐	☐	☐	☐	☐	☐	☐	Rough
Calm	☐	☐	☐	☐	☐	☐	☐	Bumpy
Disagreeable	☐	☐	☐	☐	☐	☐	☐	Agreeable
Bouncy	☐	☐	☐	☐	☐	☐	☐	Smooth
Unpleasant	☐	☐	☐	☐	☐	☐	☐	Pleasant
Comfortable	☐	☐	☐	☐	☐	☐	☐	Uncomfortable
Soothing	☐	☐	☐	☐	☐	☐	☐	Annoying
Rocking	☐	☐	☐	☐	☐	☐	☐	Smooth
Swaying	☐	☐	☐	☐	☐	☐	☐	Even
Calm	☐	☐	☐	☐	☐	☐	☐	Shaky
Uneven	☐	☐	☐	☐	☐	☐	☐	Even
Steady	☐	☐	☐	☐	☐	☐	☐	Unsteady

Figure F-1c. Ride Quality Questionnaire, Bi-Polar Descriptive Scales for Simple Alternative for "Smooth Ride" Segments

Run No. __________

Subject __________

Please check the point on the scale that best describes the ride you just experienced.

Zero Discomfort 0 — 1 — 2 — 3 — 4 — 5 — 6 — 7 — 8 — 9 Maximum Discomfort

SCALE ______

Please make a mark on each of the 12 scales below to describe the ride you just experienced.

Jolting	☐	☐	☐	☐	☐	☐	☐	Smooth
Smooth	☐	☐	☐	☐	☐	☐	☐	Jarring
Bumpy	☐	☐	☐	☐	☐	☐	☐	Smooth
Calm	☐	☐	☐	☐	☐	☐	☐	Lurching
Smooth	☐	☐	☐	☐	☐	☐	☐	Bouncy
Uncomfortable	☐	☐	☐	☐	☐	☐	☐	Comfortable
Even	☐	☐	☐	☐	☐	☐	☐	Bouncy
Jolting	☐	☐	☐	☐	☐	☐	☐	Rhythmic
Unpleasant	☐	☐	☐	☐	☐	☐	☐	Pleasant
Smooth	☐	☐	☐	☐	☐	☐	☐	Rocking
Bucking	☐	☐	☐	☐	☐	☐	☐	Smooth
Smooth	☐	☐	☐	☐	☐	☐	☐	Surging

Figure F-1c. Ride Quality Questionnaire, Bi-polar Descriptive Scales for "Lateral Event Ride" Segments.

Run No. ________

Subject ________

Please check the point on the scale that best describes the ride you just experienced.

Zero Discomfort 0 1 2 3 4 5 6 7 8 9 Maximum Discomfort

SCALE ________

Please make a mark on each of the 12 scales below to describe the ride you just experienced.

Rough	☐	☐	☐	☐	☐	☐	☐	Smooth
Smooth	☐	☐	☐	☐	☐	☐	☐	Shaky
Bumpy	☐	☐	☐	☐	☐	☐	☐	Smooth
Even	☐	☐	☐	☐	☐	☐	☐	Uneven
Comfortable	☐	☐	☐	☐	☐	☐	☐	Uncomfortable
Calm	☐	☐	☐	☐	☐	☐	☐	Bumpy
Annoying	☐	☐	☐	☐	☐	☐	☐	Soothing
Steady	☐	☐	☐	☐	☐	☐	☐	Unsteady
Unpleasant	☐	☐	☐	☐	☐	☐	☐	Pleasant
Level	☐	☐	☐	☐	☐	☐	☐	Bouncing
Agreeable	☐	☐	☐	☐	☐	☐	☐	Disagreeable
Jarring	☐	☐	☐	☐	☐	☐	☐	Rhythmic

Figure F-1c. Ride Quality Questionnaire, Bi-polar Descriptive Scales for "Continuous Rough Ride" Segments.

Run No. ____________

Subject ____________

Please check the point on the scale that best describes the ride you just experienced.

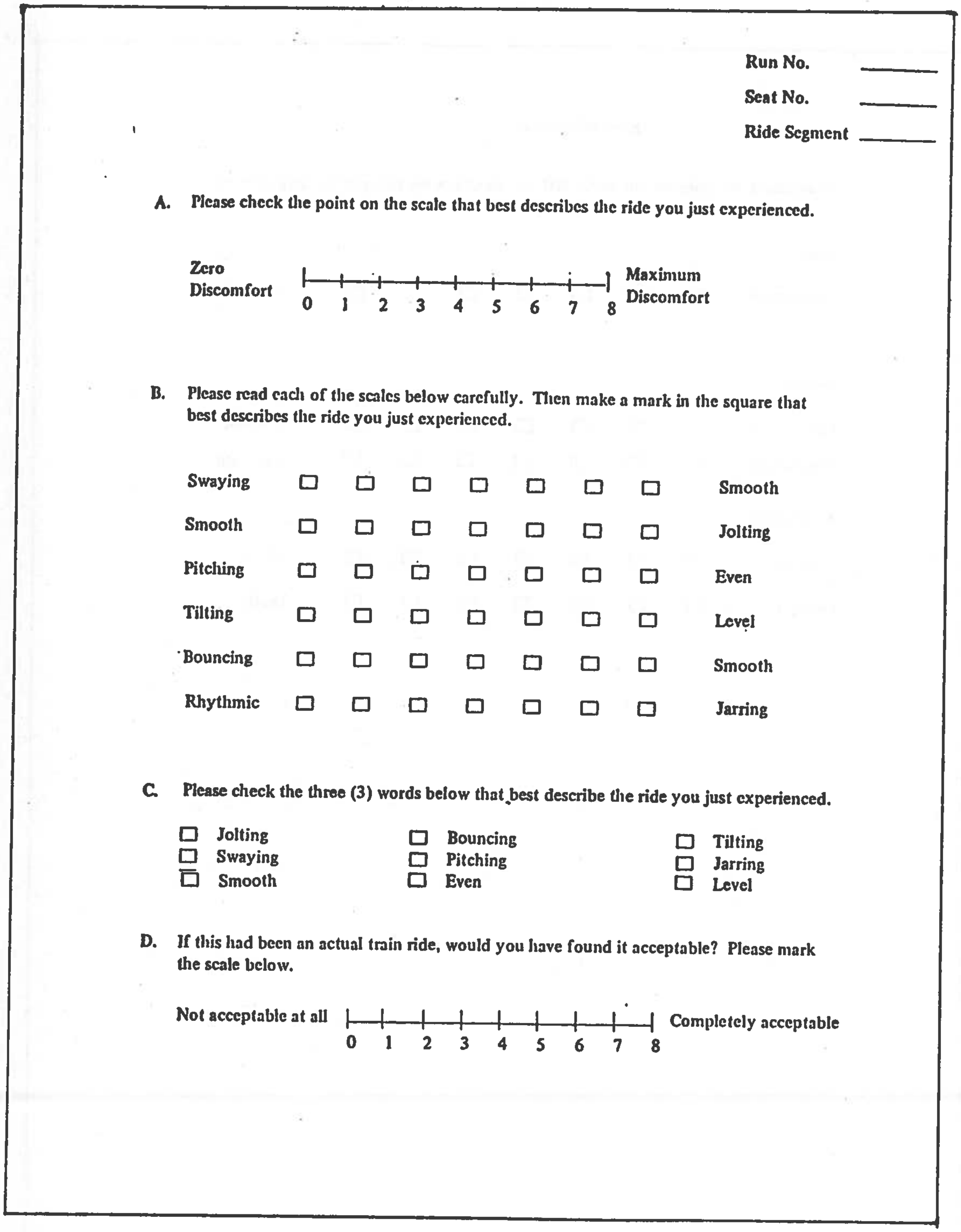
Zero Discomfort	0	1	2	3	4	5	6	7	8	9	Maximum Discomfort

SCALE ________

Please make a mark on each of the 12 scales below to describe the ride you just experienced.

Swaying	☐	☐	☐	☐	☐	☐	☐	Smooth
Even	☐	☐	☐	☐	☐	☐	☐	Swaying
Smooth	☐	☐	☐	☐	☐	☐	☐	Rolling
Smooth	☐	☐	☐	☐	☐	☐	☐	Lurching
Smooth	☐	☐	☐	☐	☐	☐	☐	Rocking
Rolling	☐	☐	☐	☐	☐	☐	☐	Calm
Pleasant	☐	☐	☐	☐	☐	☐	☐	Unpleasant
Level	☐	☐	☐	☐	☐	☐	☐	Tilting
Uncomfortable	☐	☐	☐	☐	☐	☐	☐	Comfortable
Pitching	☐	☐	☐	☐	☐	☐	☐	Even
Wobbly	☐	☐	☐	☐	☐	☐	☐	Smooth
Careening	☐	☐	☐	☐	☐	☐	☐	Calm

Figure F-1c. Ride Quality Questionnaire Bi-polar Descriptive Scales for "Roll-coupled Vibration Ride".



Run No. ______

Seat No. ______

Ride Segment ______

A. Please check the point on the scale that best describes the ride you just experienced.

Zero Discomfort 0 1 2 3 4 5 6 7 8 Maximum Discomfort

B. Please read each of the scales below carefully. Then make a mark in the square that best describes the ride you just experienced.

Swaying	☐	☐	☐	☐	☐	☐	☐	Smooth
Smooth	☐	☐	☐	☐	☐	☐	☐	Jolting
Pitching	☐	☐	☐	☐	☐	☐	☐	Even
Tilting	☐	☐	☐	☐	☐	☐	☐	Level
Bouncing	☐	☐	☐	☐	☐	☐	☐	Smooth
Rhythmic	☐	☐	☐	☐	☐	☐	☐	Jarring

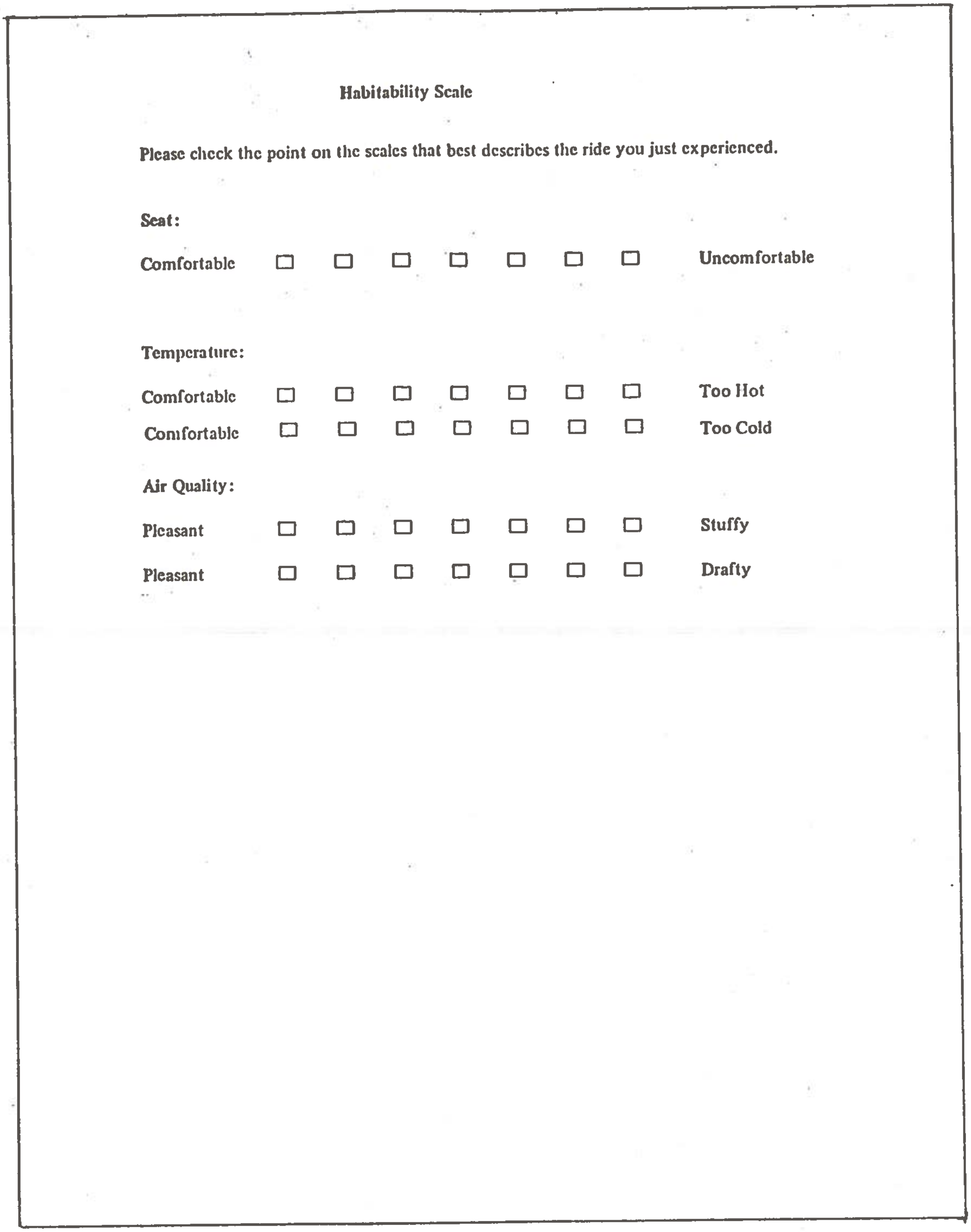
C. Please check the three (3) words below that best describe the ride you just experienced.

☐ Jolting
☐ Swaying
☐ Smooth
☐ Bouncing
☐ Pitching
☐ Even
☐ Tilting
☐ Jarring
☐ Level

D. If this had been an actual train ride, would you have found it acceptable? Please mark the scale below.

Not acceptable at all 0 1 2 3 4 5 6 7 8 Completely acceptable

Figure F-1d. Ride Quality Questionnaire, Descriptive and Acceptability Scales, Completed for Each Ride Segment after Completing the Specific Bi-polar Scales Shown in Figure F-1c.



Habitability Scale

Please check the point on the scales that best describes the ride you just experienced.

Seat:

Comfortable	☐	☐	☐	☐	☐	☐	☐	Uncomfortable

Temperature:

Comfortable	☐	☐	☐	☐	☐	☐	☐	Too Hot
Comfortable	☐	☐	☐	☐	☐	☐	☐	Too Cold

Air Quality:

Pleasant	☐	☐	☐	☐	☐	☐	☐	Stuffy
Pleasant	☐	☐	☐	☐	☐	☐	☐	Drafty

Figure F-1e. Habitability Scales

F.2 EXPERIMENT II

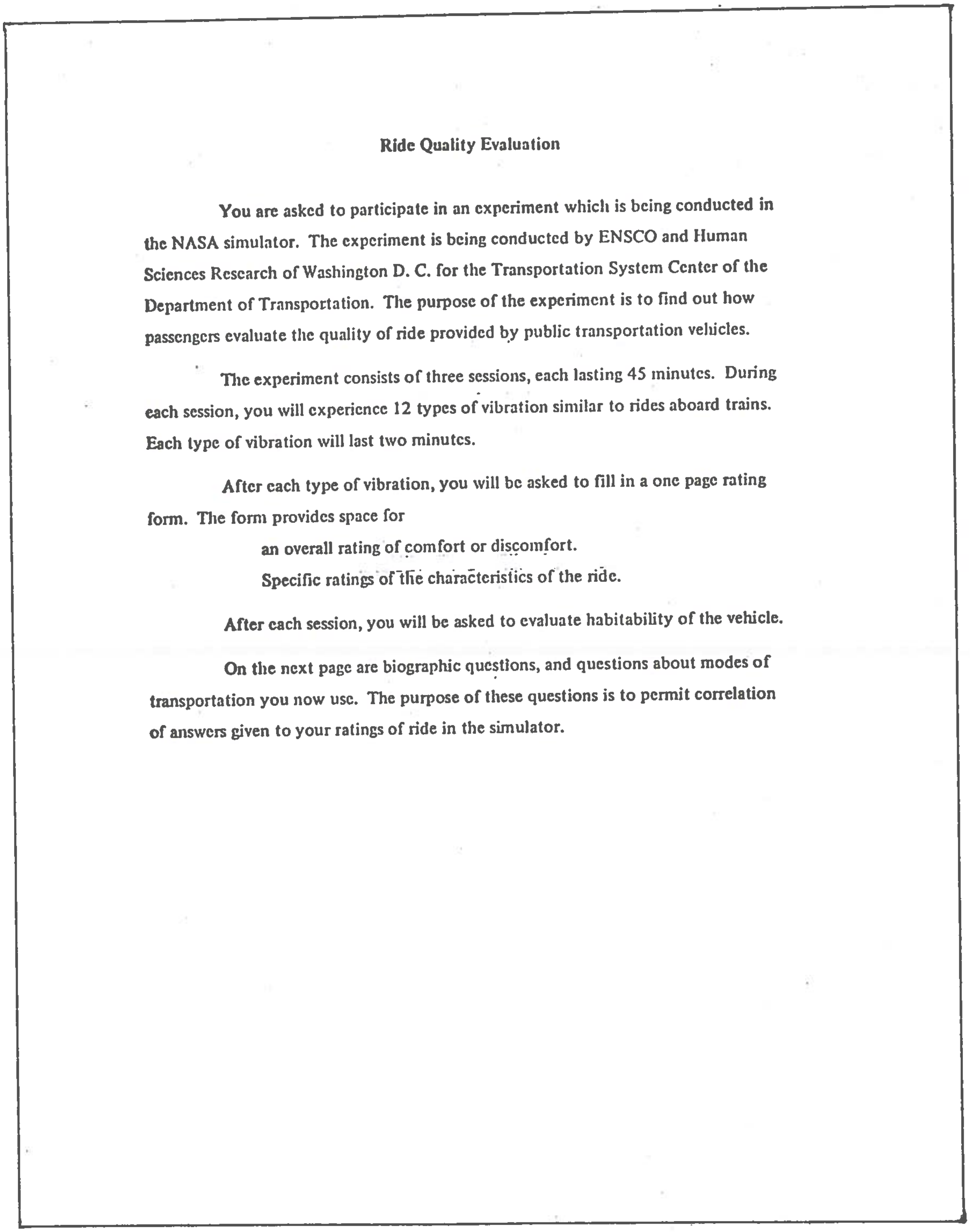
A booklet was given to each subject before each test run. This booklet contained instructions and questionnaires and was similar to that used in Experiment I. The booklet contained the following material:

Demographic Data

Ride Rating Sheets - two pages per ride; same format used for all ride segments.

Habitability Scales - Completed after all ride segments presented, but before leaving simulator.

The detailed format of the Experiment II questionnaire booklet is shown in Figure F-2.



Ride Quality Evaluation

You are asked to participate in an experiment which is being conducted in the NASA simulator. The experiment is being conducted by ENSCO and Human Sciences Research of Washington D. C. for the Transportation System Center of the Department of Transportation. The purpose of the experiment is to find out how passengers evaluate the quality of ride provided by public transportation vehicles.

The experiment consists of three sessions, each lasting 45 minutes. During each session, you will experience 12 types of vibration similar to rides aboard trains. Each type of vibration will last two minutes.

After each type of vibration, you will be asked to fill in a one page rating form. The form provides space for

an overall rating of comfort or discomfort.
Specific ratings of the characteristics of the ride.

After each session, you will be asked to evaluate habitability of the vehicle.

On the next page are biographic questions, and questions about modes of transportation you now use. The purpose of these questions is to permit correlation of answers given to your ratings of ride in the simulator.

Figure F-2a. Instructions for Experiment II

Seat Number ____________________ Sex: ☐ Male

Age __________ ☐ Female

Occupation ____________________

1. Yearly income level of parents:	Your yearly income level:
☐ Below $5,000	☐ Below $5,000
☐ $5,000 - $10,000	☐ $5,000 - $10,000
☐ $10,000 - $15,000	☐ $10,000 - $15,000
☐ $15,000 - $20,000	☐ $15,000 - $20,000
☐ Over $20,000	☐ Over $20,000

2. While in school, do you live in:

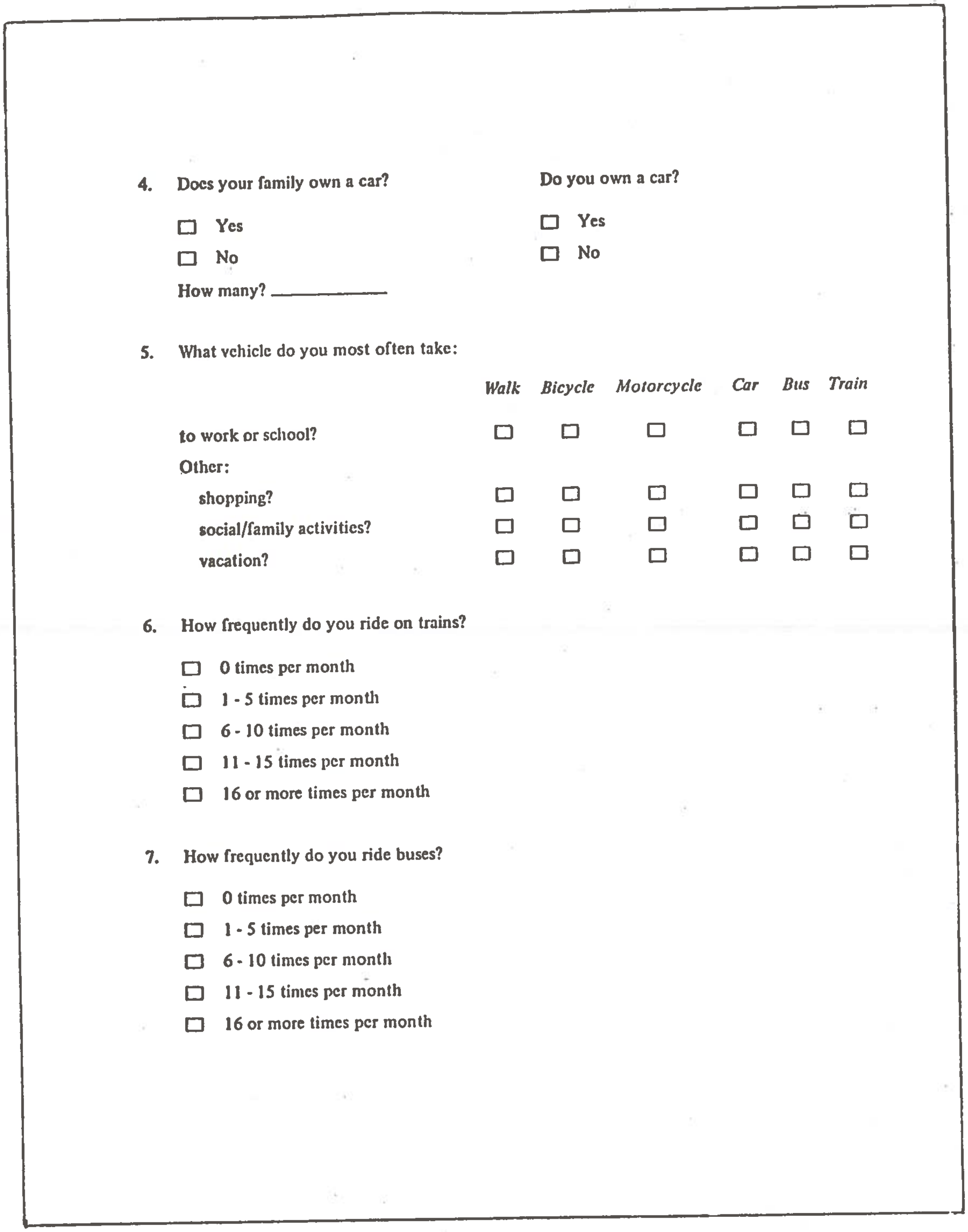
☐ a dormitory
☐ a fraternity or sorority house
☐ an apartment
☐ a room with a family other than your own
☐ at home with your family

3. While not in school, do you live in:

a. ☐ a detached house
☐ a duplex, row or townhouse
☐ an apartment
☐ other

b. ☐ an urban area
☐ a suburban area
☐ a rural area

Figure F-2b. Demographic Data Questionnaire, Page 1/3



4. Does your family own a car?

☐ Yes
☐ No
How many? ____________

Do you own a car?

☐ Yes
☐ No

5. What vehicle do you most often take:

	Walk	*Bicycle*	*Motorcycle*	*Car*	*Bus*	*Train*
to work or school?	☐	☐	☐	☐	☐	☐
Other:						
shopping?	☐	☐	☐	☐	☐	☐
social/family activities?	☐	☐	☐	☐	☐	☐
vacation?	☐	☐	☐	☐	☐	☐

6. How frequently do you ride on trains?

☐ 0 times per month
☐ 1 - 5 times per month
☐ 6 - 10 times per month
☐ 11 - 15 times per month
☐ 16 or more times per month

7. How frequently do you ride buses?

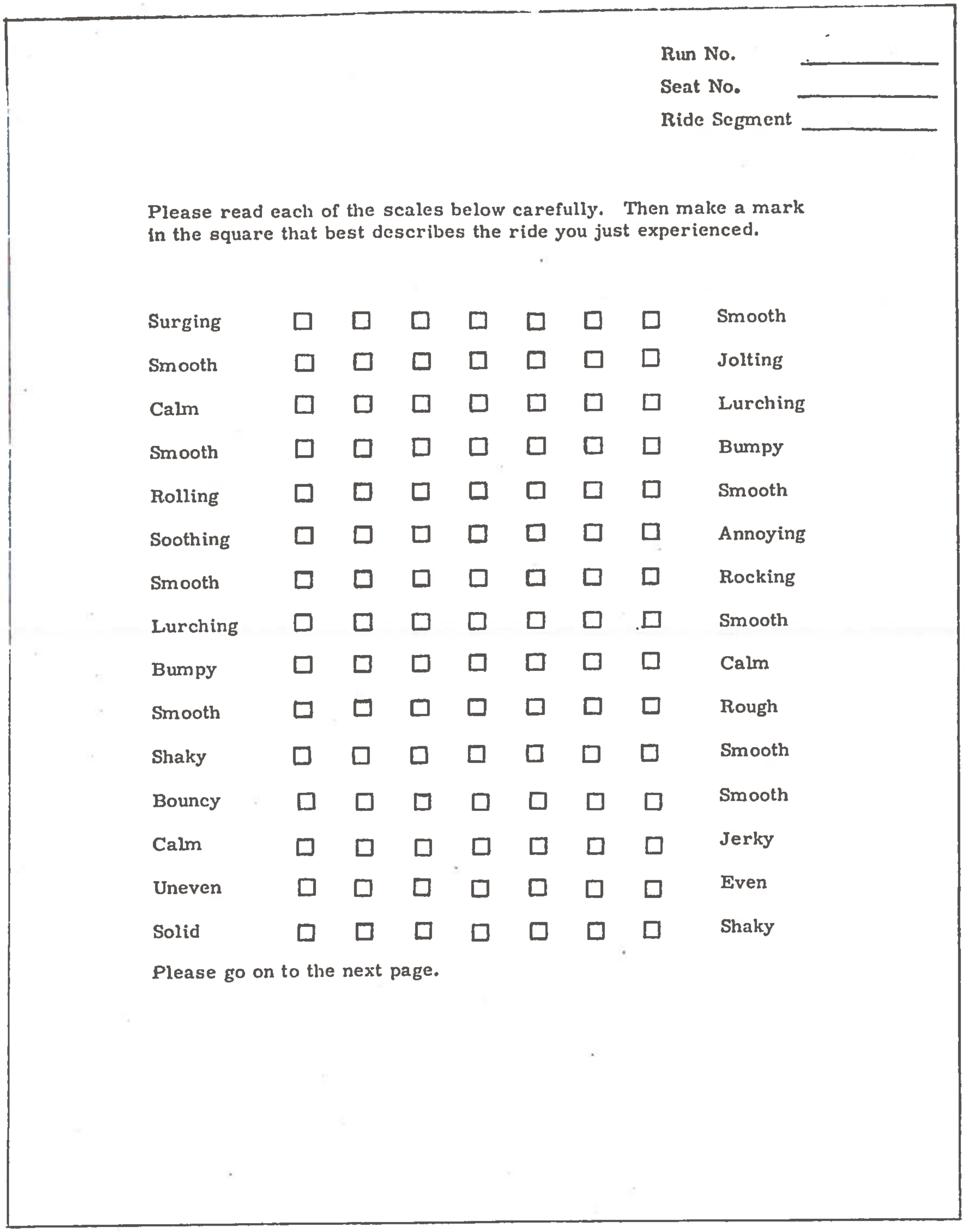
☐ 0 times per month
☐ 1 - 5 times per month
☐ 6 - 10 times per month
☐ 11 - 15 times per month
☐ 16 or more times per month

Figure F-2b continued. Demographic Data Questionnaire, Pag

8. How often do you drive or ride in a car?

- ☐ 0 times per month
- ☐ 1 - 5 times per month
- ☐ 6 - 10 times per month
- ☐ 11 - 15 times per month
- ☐ 16 - 20 times per month
- ☐ 21 or more times per month

Figure F-2b cont'd. Demographic Data Questionnaire, Page 3/3



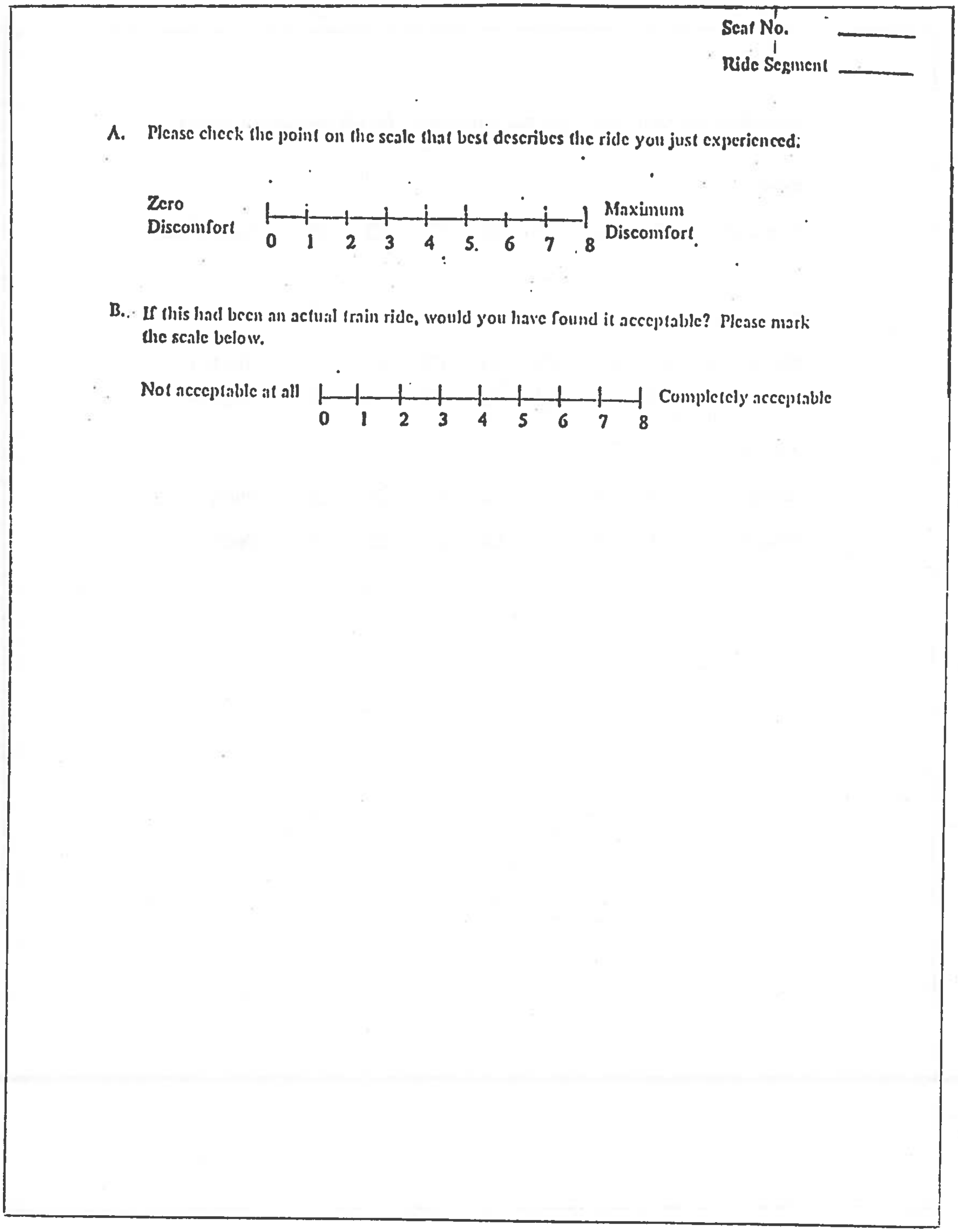
Run No. ____________
Seat No. ____________
Ride Segment ____________

Please read each of the scales below carefully. Then make a mark in the square that best describes the ride you just experienced.

Surging	☐	☐	☐	☐	☐	☐	☐	Smooth
Smooth	☐	☐	☐	☐	☐	☐	☐	Jolting
Calm	☐	☐	☐	☐	☐	☐	☐	Lurching
Smooth	☐	☐	☐	☐	☐	☐	☐	Bumpy
Rolling	☐	☐	☐	☐	☐	☐	☐	Smooth
Soothing	☐	☐	☐	☐	☐	☐	☐	Annoying
Smooth	☐	☐	☐	☐	☐	☐	☐	Rocking
Lurching	☐	☐	☐	☐	☐	☐	☐	Smooth
Bumpy	☐	☐	☐	☐	☐	☐	☐	Calm
Smooth	☐	☐	☐	☐	☐	☐	☐	Rough
Shaky	☐	☐	☐	☐	☐	☐	☐	Smooth
Bouncy	☐	☐	☐	☐	☐	☐	☐	Smooth
Calm	☐	☐	☐	☐	☐	☐	☐	Jerky
Uneven	☐	☐	☐	☐	☐	☐	☐	Even
Solid	☐	☐	☐	☐	☐	☐	☐	Shaky

Please go on to the next page.

Figure F-2c. Ride Quality Questionnaire, Bi-polar Descriptor Scales; page 1/2 for each ride segment.



Seat No. ______

Ride Segment ______

A. Please check the point on the scale that best describes the ride you just experienced:

Zero Discomfort 0 1 2 3 4 5 6 7 8 Maximum Discomfort

B. If this had been an actual train ride, would you have found it acceptable? Please mark the scale below.

Not acceptable at all 0 1 2 3 4 5 6 7 8 Completely acceptable

Figure F-2c cont'd. Ride Quality Questionnaire, Comfort and Acceptability Scales; page 2/2 for each ride segment.

Please check the point on the scales that best describes the ride you just experienced.

Seat:

Comfortable	☐	☐	☐	☐	☐	☐	☐	Uncomfortable

Temperature:

Comfortable	☐	☐	☐	☐	☐	☐	☐	Too Hot
Comfortable	☐	☐	☐	☐	☐	☐	☐	Too Cold

Air Quality:

Pleasant	☐	☐	☐	☐	☐	☐	☐	Stuffy
Pleasant	☐	☐	☐	☐	☐	☐	☐	Drafty

Figure F-2d. Habitability Scales

APPENDIX G

REPORT OF INVENTIONS

A diligent review of the work performed under this contract reveals that the innovative use of word pairs in the assessment of ride quality as conceived at TSC proved effective. Beyond that, there were no other discoveries, improvements, or inventions.

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