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DEVELOPMENT AND APPLICATION OF RIDE-QUALITY CRITERIA

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16. Abstract

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ABSTRACT

A program for the development of ride-quality vibration criteria applicable to the design and evaluation of air and surface transportation systems is described. Consideration is given to the magnitude of vehicle vibration experienced by the passenger, the frequency of vibration, the direction of vibration, and the influence of seat dynamics on passenger response. Comparative vibration measurements are presented for a variety of air and surface transportation systems. In addition, simulator data on seat dynamics and passenger response are presented. Results suggest the relative merits of various physical descriptors and measurement locations for characterizing the vibration in terms suitable for the design and/or evaluation of transportation systems.

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INTRODUCTION

The vibrational characteristics of current transportation systems are well recognized as important to the comfort of vehicle passengers. For future transportation systems, these vibrational characteristics may be a primary design consideration in developing vehicles which will be acceptable to the passengers. For these reasons, it is necessary to fully evaluate the influence of vehicle vibration on passenger acceptance. Essential to this evaluation is an improved understanding of relations between the vibrational properties (amplitude, frequency, direction) of the transportation system and of the psychological responses of the passenger. To provide this understanding, a ride-quality criteria program consisting of field measurements and laboratory simulation studies is being conducted at the NASA Langley Research Center. The objectives of this program are to better define the vibration environment of air and surface transportation systems and to examine the effects of vibration on passenger comfort.

Numerous studies have been conducted to examine the effects of vehicle vibration on passenger comfort (1-5, for example).* However, most of these studies have been limited to single axis inputs over a limited range of vibration amplitude and frequency. As a consequence, a comprehensive understanding of the effects of vibration on comfort does not exist. In particular, methods for assessing the combined effects of vibrational level, frequency, direction

*Numbers in parentheses designate References at end of paper.

(axis effects), and seat dynamics of the type encountered in transportation systems are not well understood. This lack of understanding has hindered the development and acceptance of simple descriptors for characterizing the vibration environment of vehicles and the subsequent development of a comprehensive data base for current vehicle systems.

The purpose of this paper is to describe the ride-quality program and to present comparative vibration data obtained on a variety of air and surface transportation vehicles along with simulator data on seat dynamics and passenger response. The data are presented in terms of several physical descriptors and represent a sizable data base for the assessment of future vehicles and/or the development of ride-quality vibration criteria.

RIDE-QUALITY PROGRAM

The purpose of the ride-quality program is to develop vibration criteria applicable to the design and/or assessment of air and ground transportation systems. The approach consists of field measurements and laboratory simulator studies to determine relationships between the physical environment of the transportation system and the psychological response or comfort of the passenger. To date, multiaxis vibration measurements have been obtained from field measurements on a wide variety of vehicle types. These data suggest the frequency and amplitude range to be considered in developing criteria as well as the relative importance of direction (axis) effects. Furthermore, the measurements serve as a data base for the assessment of the ride quality of a particular vehicle relative to other types of vehicles in common usage. Comparative data, in terms of several physical descriptors, are presented in the next section for a variety of vehicles. The simulator program utilizes the LRC-Passenger Ride-Quality Apparatus (PRQA) which is a three-degree-of-freedom system (6) and is aimed at isolating and quantifying those properties of seat/passenger vibration that affect ride quality. Emphasis at present is on combined frequency and multiaxis effects. It should be noted that the field program and simulator studies are currently limited to the effects of vibration on ride quality. An integration of the vibration effects with other factors such as noise, temperature, service, and so forth, will be required to gain a more complete understanding of passenger acceptance.

VEHICLE VIBRATION MEASUREMENTS - Vibration measurements are obtained (7) using the specially developed portable, battery operated, instrumentation system shown in Figure 1. The system consists of one or more acceleration packages each containing three linear servo accelerometers to measure vibration in the vertical, lateral, and fore-and-aft directions. The accelerometer data are recorded on a multichannel FM recorder and later digitized for frequency and amplitude analyses using a time series analysis program (8). The quasi-steady values of acceleration are removed from the recorded signals by passing the data through a high pass filter which excludes values below 0.1 Hz.

In examining the vibration environment of a vehicle, the acceleration time history for a particular event, the amplitude of the vibration, and the frequency characteristics are of importance. Figure 2 is an example of such information recorded in the vertical direction an a CTOL airplane during ground taxi. The acceleration time history is shown along with an acceleration amplitude histogram and power spectral density (PSD) function. In addition to providing important information for assessing comfort, the acceleration time history and the frequency analysis (PSD) are often useful in diagnosing the source of the vibration input. For example, the acceleration time history may be used to identify a rough area in the runway whereas the PSD may provide information on the wavelength of the input or the characteristic response frequencies of the vehicle.

SIMULATOR STUDIES - A photograph of the Passenger Ride-Quality Apparatus (PRQA), which is one of three Langley Research Center simulators used for passenger acceptance studies, is shown in Figure 3. As shown, the simulator is configured to represent the interior of an aircraft and can be fitted with four first-class seats (as illustrated) or with six tourist-class seats. The simulator (9) is driven by hydraulic actuators which provide motion in the vertical, lateral, and roll directions. The hydraulic drive mechanism is shown in Figure 4 along with the performance specifications in terms of acceleration (Fig. 5). Single or multiple axis inputs can be obtained by oscillators or actual field recorded tapes over a frequency range from 0 to 30 Hz. The simulator has been used, for example, to study seat characteristics (transmissibility) as well as the response of subjects to sinusoidal inputs over a wide range of frequencies in the vertical and lateral directions.

RESULTS AND DISCUSSION

Basic to the development of ride-quality vibration criteria is a description of the physical stimuli which includes the vibration descriptors and the measurement location. There are, for example, several options for quantifying the amplitude and/or amplitude-frequency characteristics of the vibration. Even more fundamental perhaps are the choices of sensor location which include the floor of the passenger compartment, the seat, the passenger himself, and the combinations of these locations. In an effort to examine a variety of possible descriptors as well as to provide a comparative data base for future use, measured data are presented in the next section for a variety of vehicles and passenger seats.

PHYSICAL DESCRIPTORS - Among the candidate units for describing the vibration association with a particular vehicle, the following descriptors are of interest and were selected for this study:

g_p	the maximum amplitude of vibratory acceleration associated with a selected time history;
g_{rms}	the overall root-mean-square value of acceleration for a selected frequency band (0.1 to 30 Hz for this study);
$g_{\ell 10}$	the level of vibratory acceleration that is exceeded 10 percent of the time;
g_w	the root-mean-square value of the acceleration resulting from an acceleration signal that is weighted or filtered to better reflect human response to vibration; and,
$g_{1/3\ oct.}$	the root-mean-square value of acceleration occurring in selected frequency bands such as 1/3 octave bands.

The values of these descriptors may in some cases vary depending upon the time duration of the measurement sample. For this paper, all data were obtained from samples having a duration of approximately 2 minutes.

Sample data for the take-off, landing, and cruise conditions of a CTOL aircraft are shown in Figure 6 to illustrate the above acceleration descriptors. All measurements were made at the floor of the passenger compartment near the c.g. of the aircraft. The levels presented represent the maximum value observed during several normal operations. The weighted values, g_w, were obtained by filtering the data as recommended by the International Standards Organization (ISO) to reflect recommended equal comfort contours (10), Figure 7. The data indicate that the highest values of acceleration occur during landing and take-off operations as might be anticipated. Furthermore, the vertical vibration levels are considerably higher than the lateral levels.

These general relationships are borne out quite consistently by each of the descriptors of acceleration level. The consistency of these units will be examined in more detail in the following section wherein the levels of cruise acceleration are examined for a variety of vehicles.

COMPARATIVE VEHICLE RESPONSE DATA - Comparative data obtained on a number of vehicles are presented in Figures 8 through 13 in terms of the various descriptors. The vehicles are ranked according to the maximum level of vertical acceleration. The range of g_p observed in examining numerous 2-minute data samples for each of the vehicles is presented in Figure 8. A comparison across the various vehicles suggest that the max values of g_p cover a range of about 3 to 1 ($0.15g < g_p < 0.5g$) in the vertical direction. In general, the vertical levels are higher than the lateral values and the ground vehicles have higher acceleration than the aircraft. A similar trend is noted in terms of g_{rms}, Figure 9. Again the maximum values of g_{rms} cover a range of about 3 to 1 in the vertical direction. In terms of $g_{\ell 10}$, Figure 10, the vehicle ranking with the exception of the helicopter is identical to that obtained with g_{rms}. The relatively high values of $g_{\ell 10}$ associated with the helicopter are due to discrete frequency vibration observed at the blade passage frequency.

The vehicle vibration data are presented in Figures 11 through 13 in terms of descriptors which reflect both the amplitude and the frequency of the vibration. In Figure 11, for example, the acceleration is weighted according to the ISO equal comfort contours (Fig. 7). Data are presented for the vertical direction only. It is noted that the values of g_w are lower than the values of g_{rms} (unweighted) as would be expected; however, the vehicle ranking remains approximately the same. On Figures 12 and 13, the frequency content is displayed more explicitly in terms of frequency bands. In Figure 12, the acceleration values are presented in terms of the ratio of acceleration occurring in the band from 0.1 to 4 Hz to the overall g_{rms}. The aircraft acceleration, for example, is seen to be predominantly in the lower frequency band while several of the ground vehicles have considerable vibration energy above 4 Hz. These findings are further amplified in Figures 13(a) and 13(b) in which 1/3-octave band data are presented for the surface vehicle and aircraft, respectively. The 1/3-octave amplitude-frequency distribution provides a clear picture of the vibratory frequency which is useful in determining the source of vibration.

In considering the various descriptors, the single units such as g_p, g_{rms}, $g_{\ell 10}$, and g_w all appear to provide a simple, relatively consistent or similar description of the ride and may be adequate for assessing ride quality in many applications. The selection of a preferred descriptor will depend upon the specific application as well as upon the development of more information on subjective response to vibration. For example, g_p may be preferred for examining airplane landing vibration whereas g_w may be preferred for examining longer term cruise conditions. For examining the source of vibration, the narrow-band analyses such as PSD of the 1/3-octave analyses are useful. In summary, the data of Figures 8 through 13 are believed to represent a relatively large data base when compared to previously published data on vehicle vibration. The data may be used for a comparative assessment of the ride quality of a particular vehicle of interest relative to the vehicles presented herein or in specifying design criteria for future systems in terms of currently acceptable vehicles.

SEAT/PASSENGER RESPONSE - The physical data presented in the previous sections have been obtained on the floor of the vehicle. In order to have a better understanding of how the measurements taken at the floor of the vehicle compare to the levels actually experienced by the passenger, studies were conducted with the simulator (PRQA) to determine the transmissibility of the various seats. Tourist-class, first-class, and bus seats were examined with seated passengers for single axis sinusoidal inputs in the vertical and lateral directions. The acceleration measured at the seat/passenger interface is shown in Figure 14 in terms of the amplitude response ratio (ratio of seat acceleration to floor acceleration) for a range of sinusoidal input frequencies. As noted, the resonant frequency in the vertical direction is in the range of 4 to 7 Hz with a maximum amplification of 1.4. For lateral inputs, an amplification of about 1.5 is observed in the frequency range of 2 to 3 Hz. By coincidence, the area of greatest human sensitivity, according to the ISO standards, also occurs in these regions as shown on the figure. The importance of considering seat transmissibility in the development of ride-quality criteria is currently under study in a simulator program wherein subjective ride-quality measurements are being compared with both seat and floor measurements.

Illustrative subjective results obtained during the seat transmissibility study are shown in Figure 15. Passenger response is presented in terms of frequency and amplitude for vertical and lateral sinusoidal inputs. The vibration was rated as either "acceptable" or "unacceptable" by the passengers and the results are presented in terms of the percentage of subjects rating the ride as acceptable. The trends of the data are similar to the ISO comfort boundaries. The data (based on sinusoidal inputs) suggest that rms levels of floor acceleration should be less than 0.035g in the regions of greatest sensitivity to obtain a ride quality acceptable to the majority of the passengers.

Comprehensive results of this type will be particularly useful in interpreting the physical data recorded on vehicles as well as selecting the most relevant measurement locations and physical descriptors of the ride.

SUMMARY

A program consisting of field measurements and laboratory simulator studies to determine ride-quality vibration criteria suitable for the design and/or evaluation of transportation systems is being conducted. Vertical and lateral acceleration data measured in the passenger compartment of a variety of vehicles during cruise condition are presented. In addition, simulator data on the dynamic characteristics of seats and, to a limited extent, the subjective response of passengers to sinusoidal inputs are presented.

The results of the field measurements are presented in terms of several acceleration amplitude and amplitude-frequency descriptors. The relative merits of these various descriptors can be judged by the reader based upon his needs and/or experience with the ride quality of the vehicles under study. Furthermore, the results presented in terms of several descriptors serve as a data base for assessing the ride of an existing or future system relative to vehicles in current operation.

In considering seat/passenger response, it is shown that the actual vibration sensed by the passenger may be amplified or attenuated by the seat depending upon the vibration frequency. The importance of including seat dynamics in the development of ride-comfort criteria is currently under study in a related simulator program. The results of this program should provide insight for describing single as well as combined axis vibration in terms which include the psychological aspects of human comfort.

REFERENCES

1. Symposium on Vehicle Ride Quality, Langley Research Center, Hampton, Virginia, July 6-7, 1972, NASA TM X-2620, 1972.

2. Ira D. Jacobson, "Environmental Criteria for Human Comfort - A Study of the Related Literature." NASA CR-132424, 1974.

3. J. C. Guignard and P. F. King, "Aeromedical Aspects of Vibration and Noise." AGARDograph No. 151, 1972.

4. James F. Parker, Jr., and Vita R. West (Managing Editors), Bioastronautics Data Book. NASA SP-3006, 1973.

5. Ralph W. Stone, Jr., "An Elementary Psychophysical Model to Predict Ride Comfort in the Combined Stress of Multiple Degrees of Freedom." Presented at the AGARD Aerospace Medical Panel Specialists' Meeting (Oslo, Norway), April 22-25, 1974.

6. David G. Stephens and Sherman A. Clevenson, "The Measurement and Simulation of Vibration for Passenger Ride Quality Studies." NOISEXPO Conference Proceedings, Chicago, Illinois, September 11-13, 1973, pp. 86-92.

7. John J. Catherines, Sherman A. Clevenson, and Harland F. Scholl, "A Method for the Measurement and Analysis of Ride Vibrations of Transportation Systems." NASA TN D-6785, 1972.

8. Robert C. Ward, "Dynamic Data Analysis Techniques Used in the Langley Time Series Analysis Computer Program." NASA TM X-2160, 1971.

9. S. A. Clevenson and J. D. Leatherwood, "On the Development of Passenger Ride Acceptance Criteria." Presented at the 43rd Shock and Vibration Symposium, Pacific Grove, California, December 5-7, 1972.

10. "Guide for the Evaluation of Human Exposure to Whole-Body Vibration." Draft International Standard ISO/DIS 2631, International Organization for Standardization.

FIGURE CAPTIONS

Figure 1. Field measuring and recording system.

Figure 2. Sample of CTOL airplane vertical vibration data for ground taxi condition.

Figure 3. Ride-quality simulator.

Figure 4. Three-degree-of-freedom simulator drive mechanism.

Figure 5. Ride-quality simulator vibration capability.

Figure 6. Sample CTOL vertical acceleration data in terms of various physical descriptors.

Figure 7. ISO reduced comfort boundaries for vertical vibration.

Figure 8. Comparative data in terms of maximum amplitude of vibratory acceleration.

Figure 9. Comparative data in terms of the overall root-mean-square value of acceleration.

Figure 10. Comparative data in terms of the vibratory level that is exceeded 10 percent of the time.

Figure 11. Comparative data in terms of the weighted root-mean-square value of vertical acceleration.

Figure 12. Comparative vertical acceleration data in terms of frequency bands.

Figure 13. Comparative vertical acceleration data in terms of 1/3-octave bands.
(a) Surface vehicles.
(b) Aircraft.

Figure 14. Seat transmissibility.

Figure 15. Passenger acceptability. Tourist-class seats.

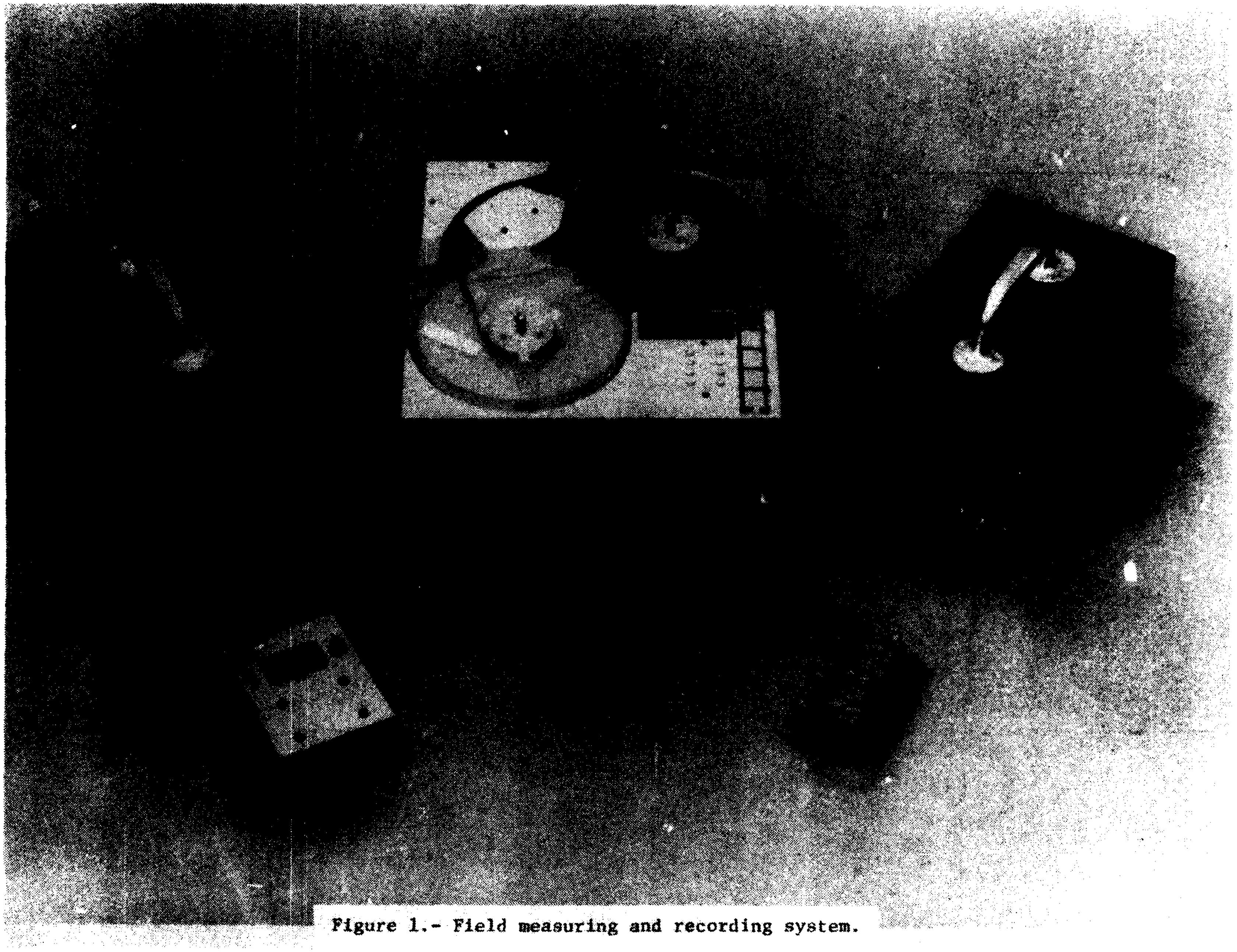
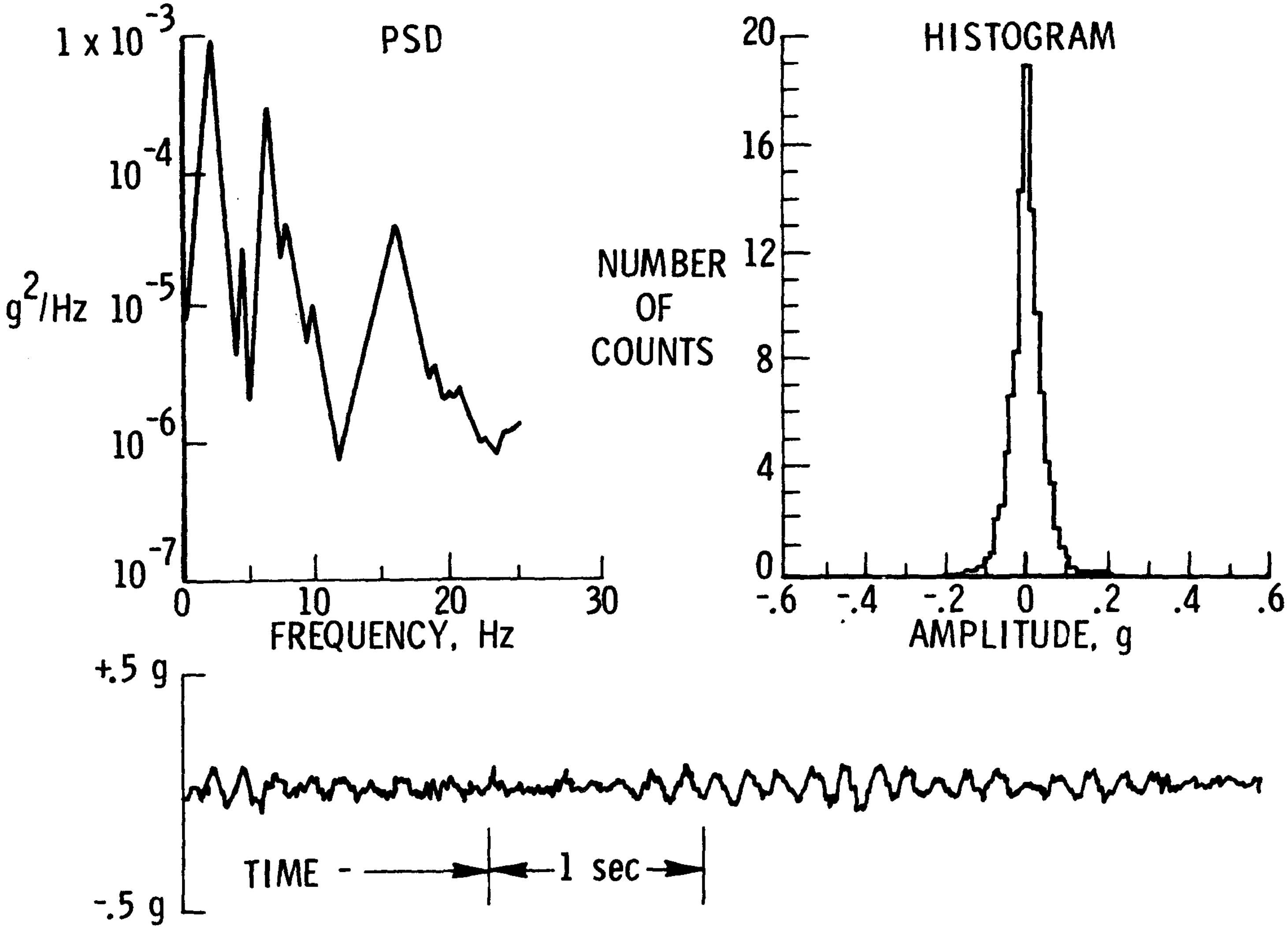


Figure 1.- Field measuring and recording system.



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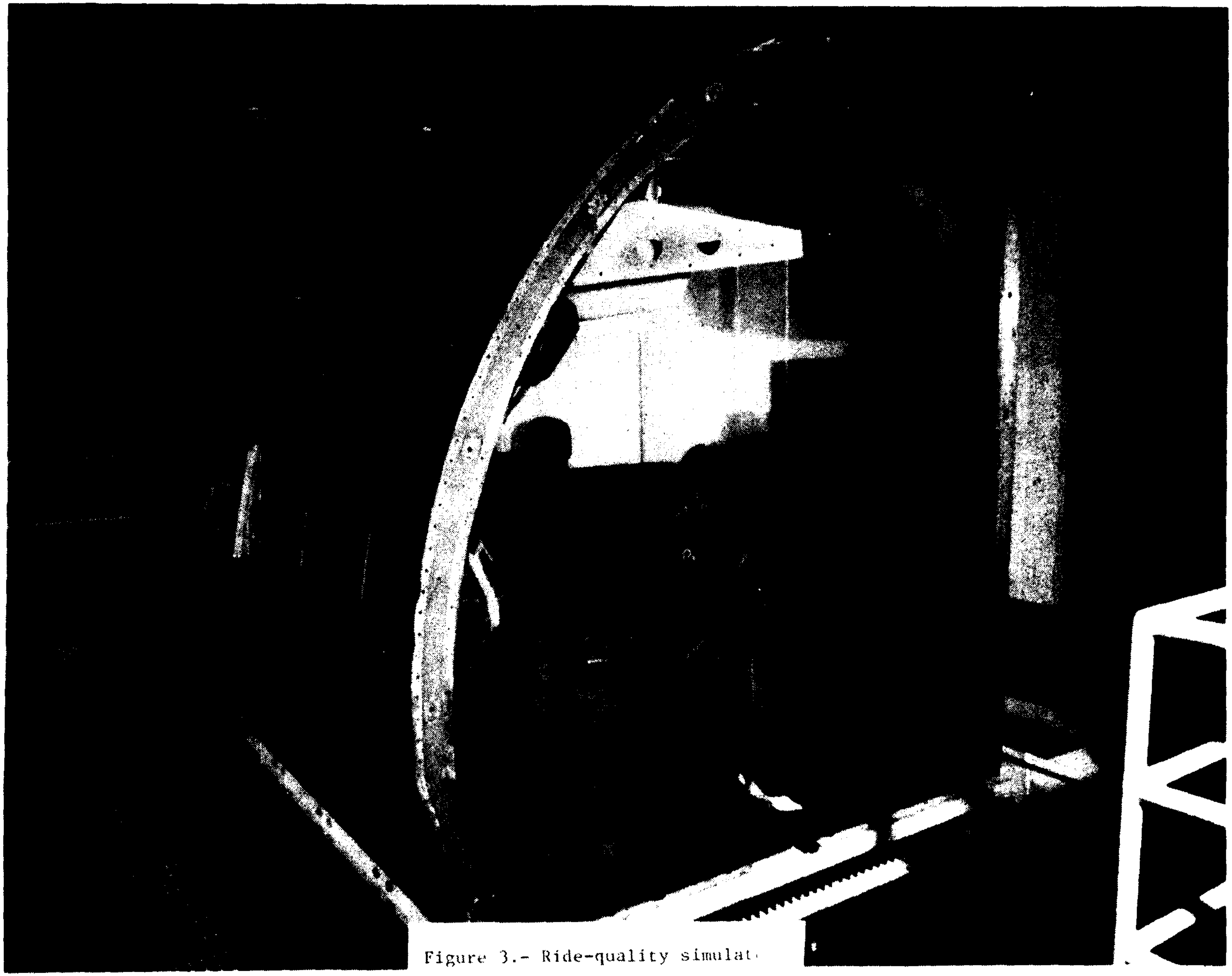


Figure 3.- Ride-quality simulat

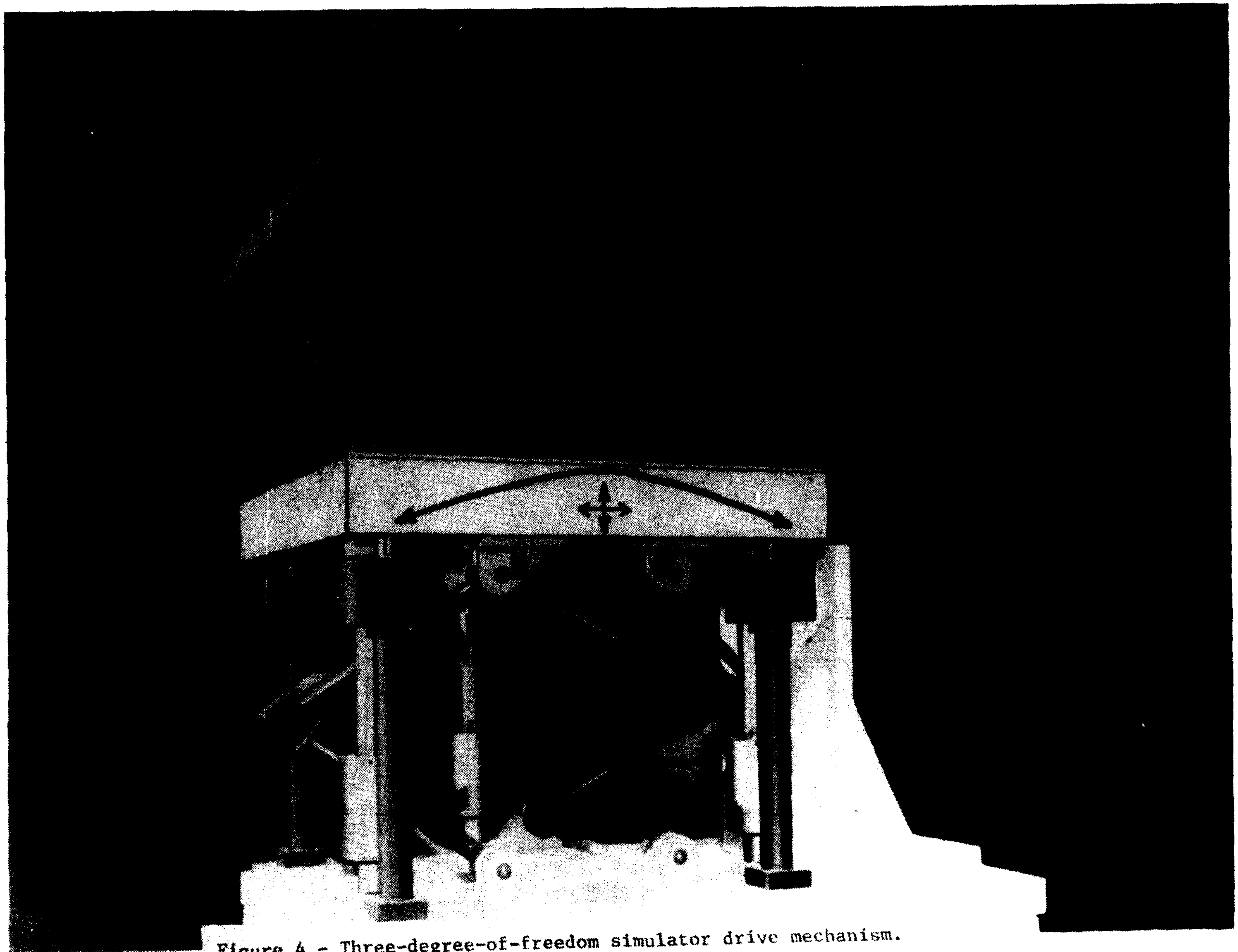
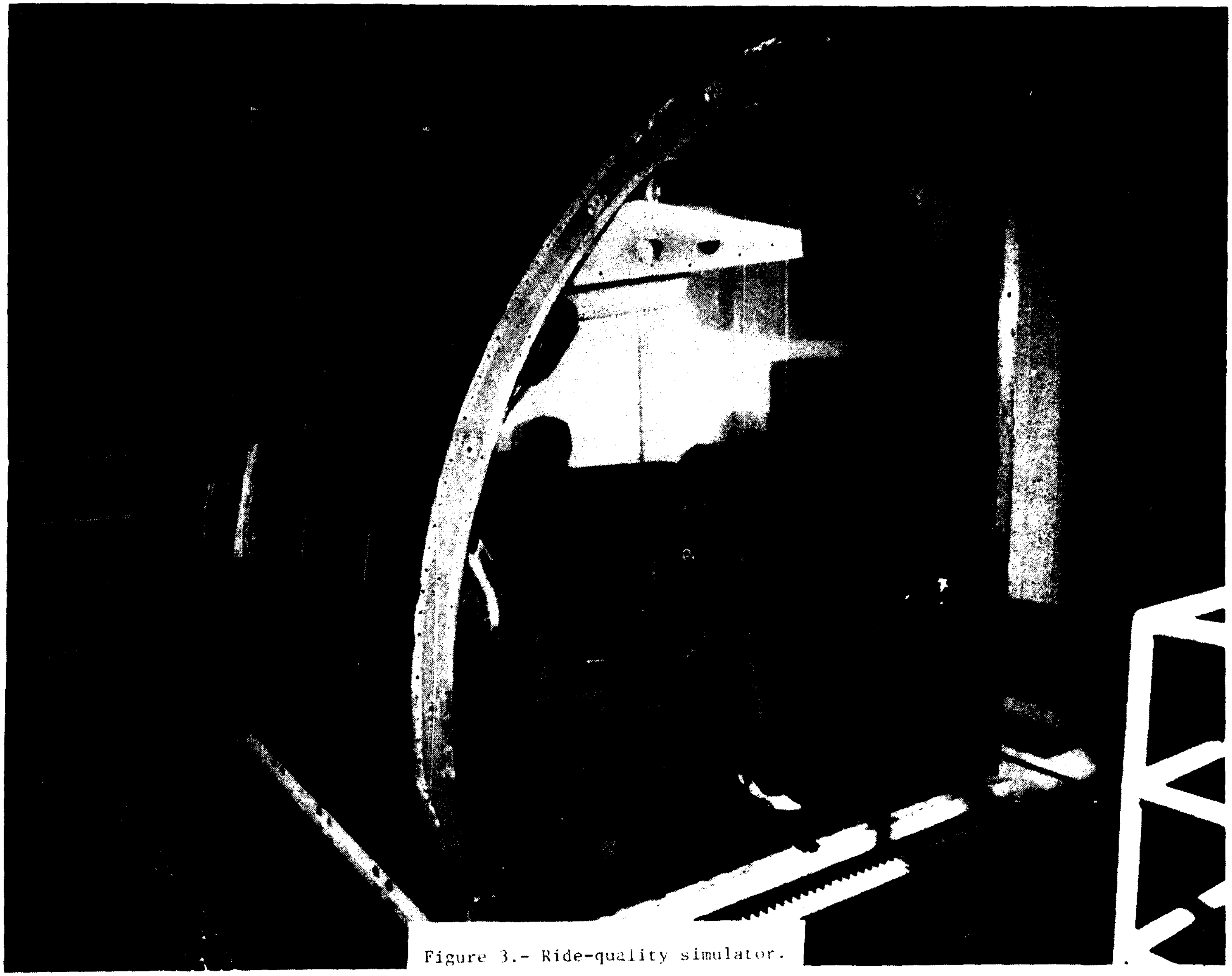


Figure 4.- Three-degree-of-freedom simulator drive mechanism.



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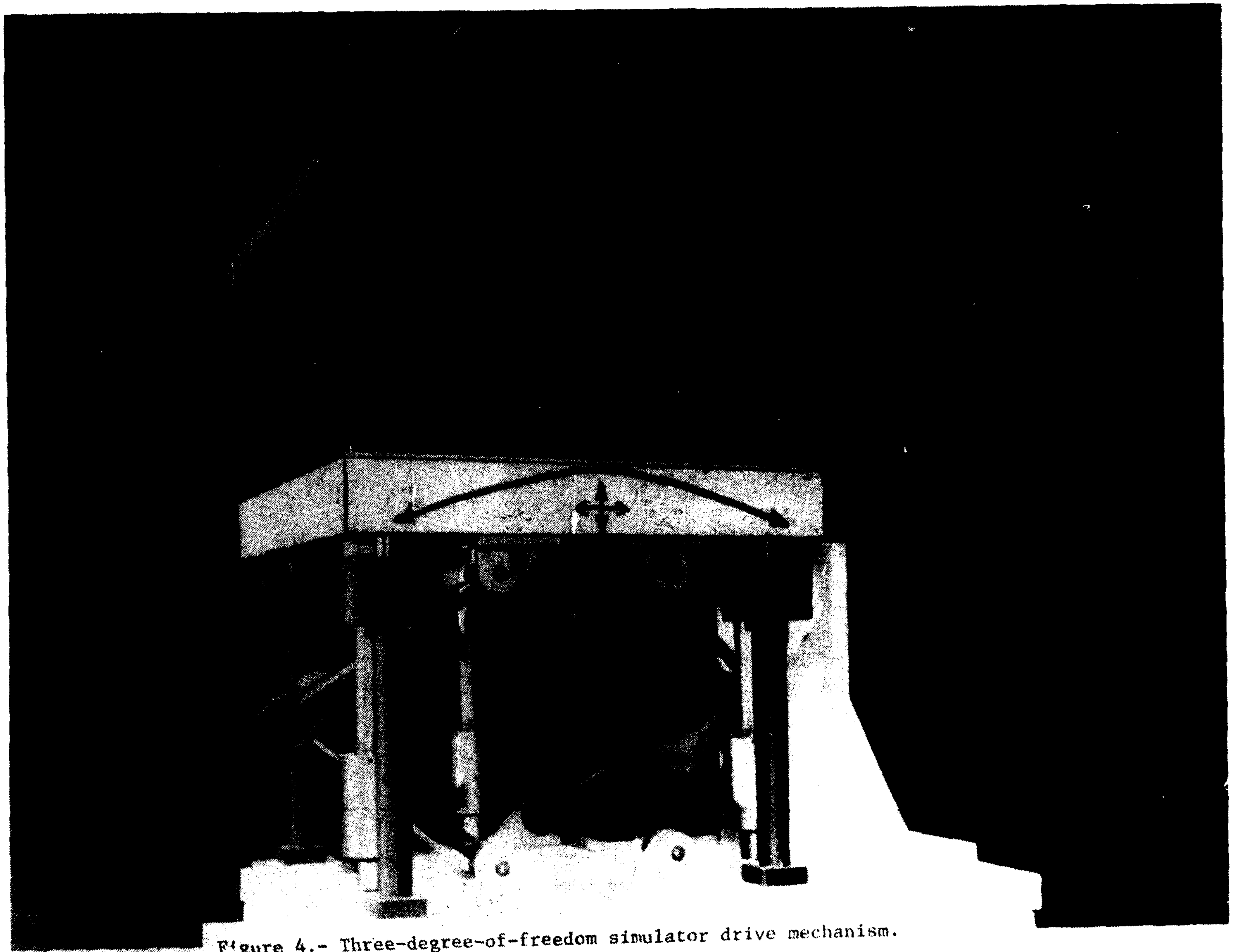

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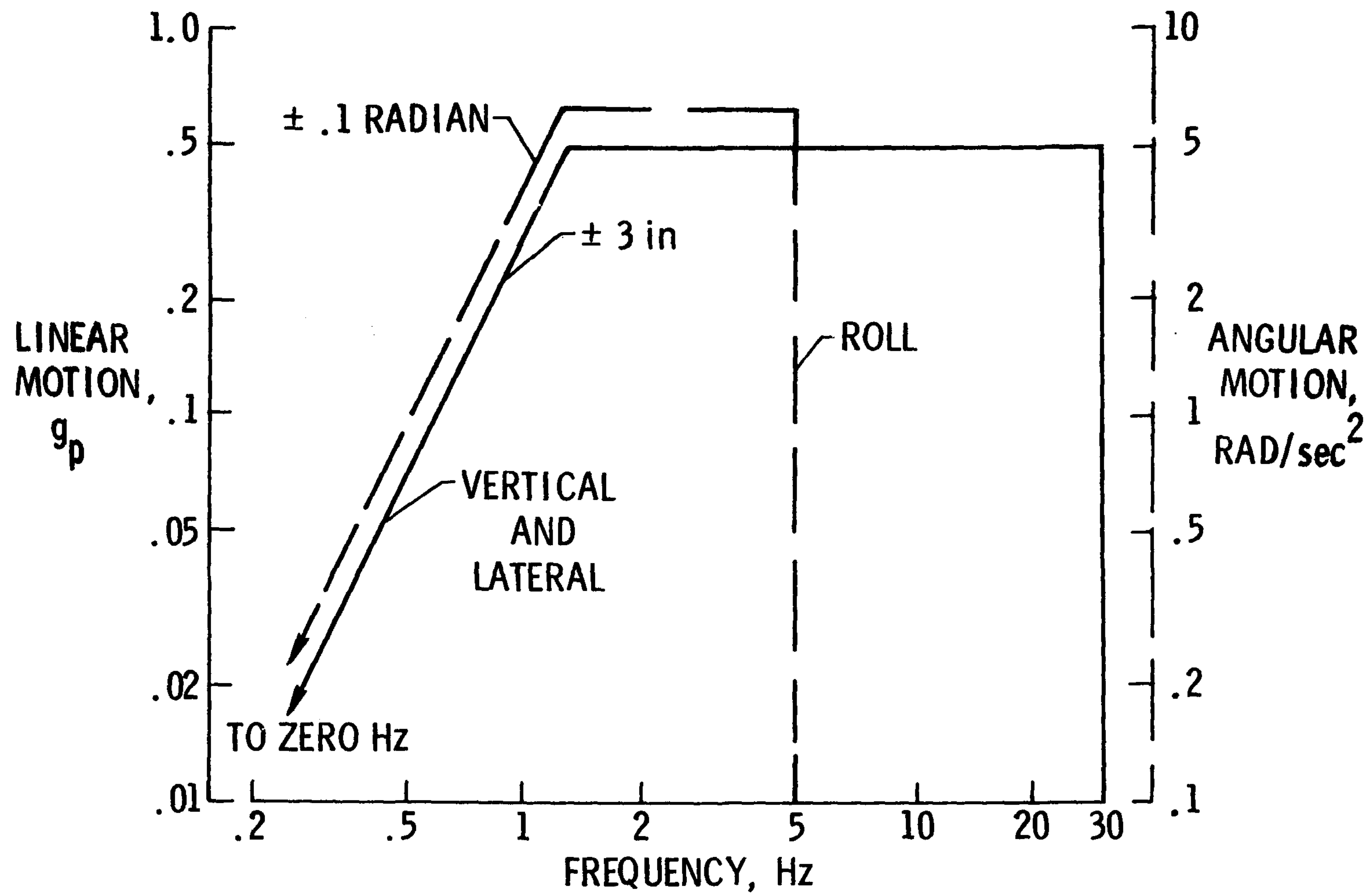

Figure 5.- Ride-quality simulator vibration capability.

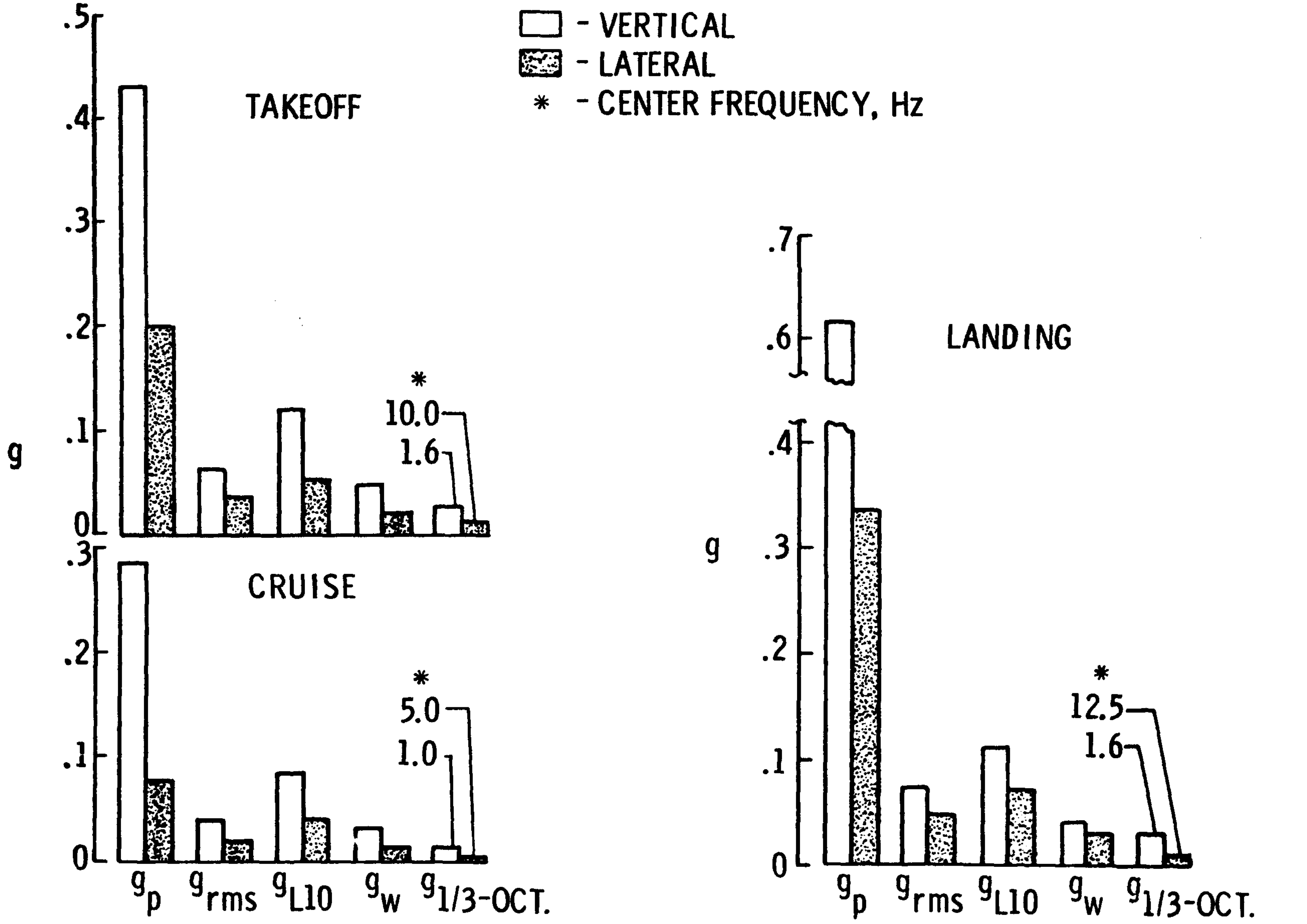

Figure 6.- Sample CTOL vertical acceleration data in terms of various physical descriptors.

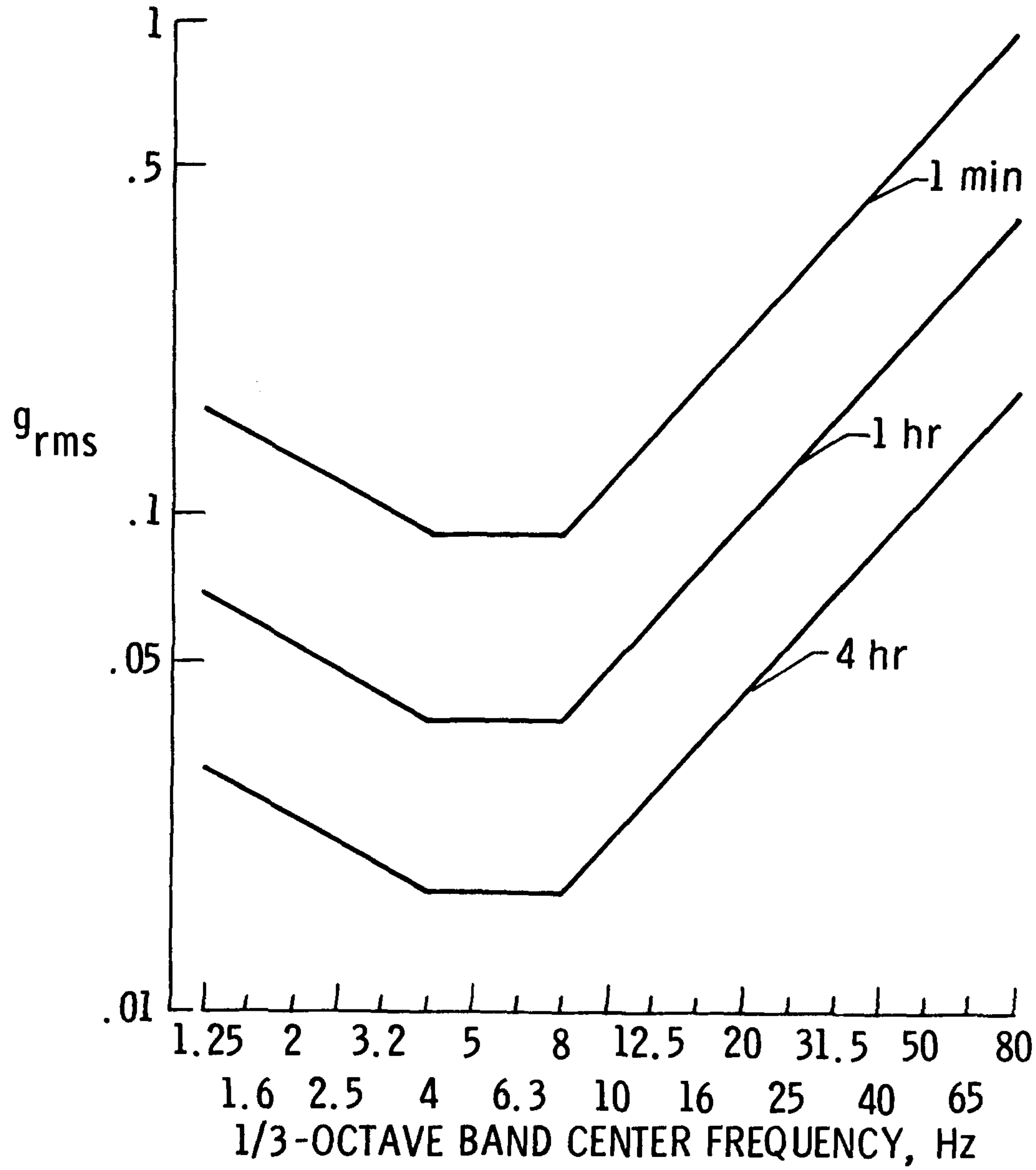

Figure 7.- ISO reduced comfort boundaries for vertical vibration.

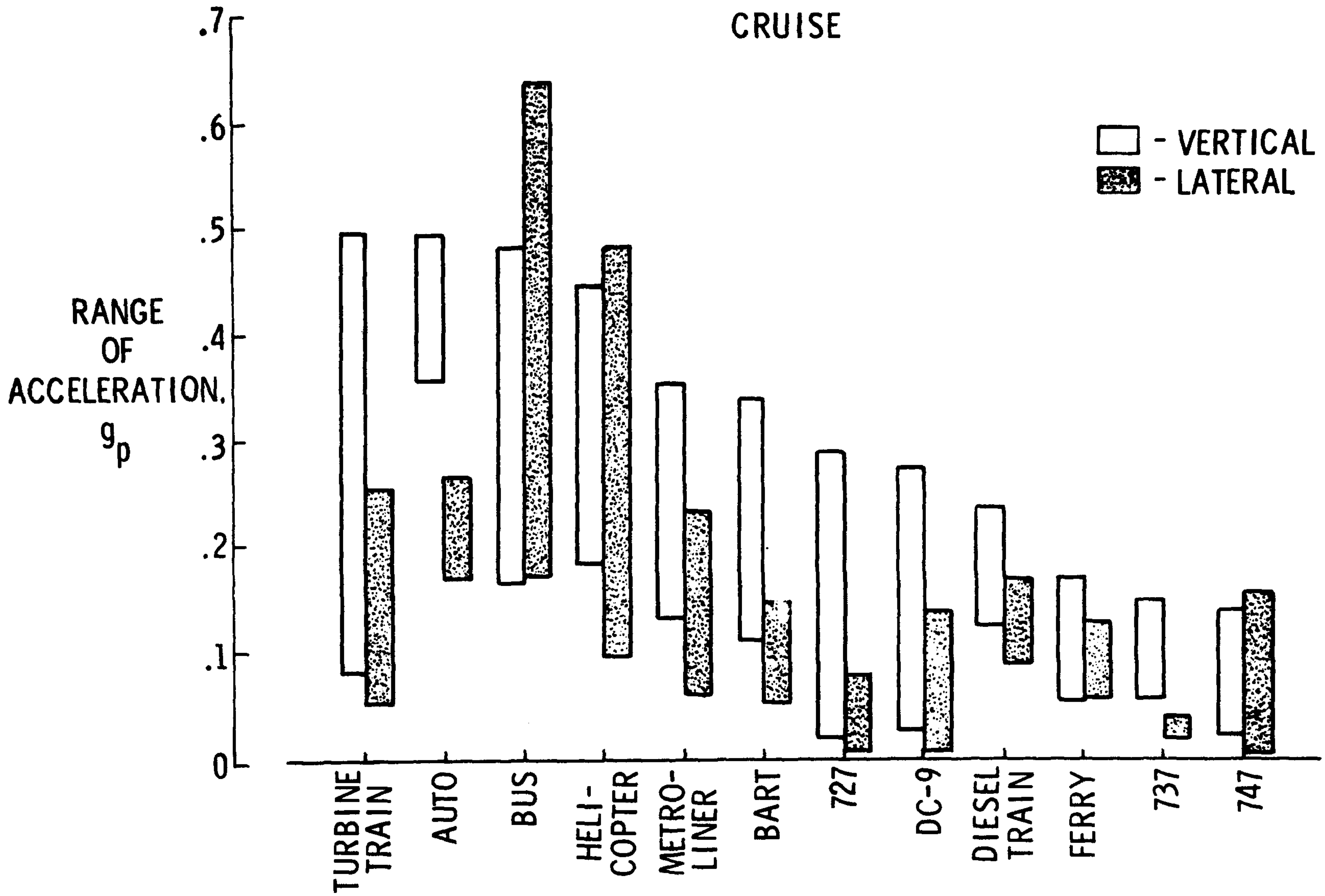

Figure 8.- Comparative data in terms of maximum amplitude of vibratory acceleration.

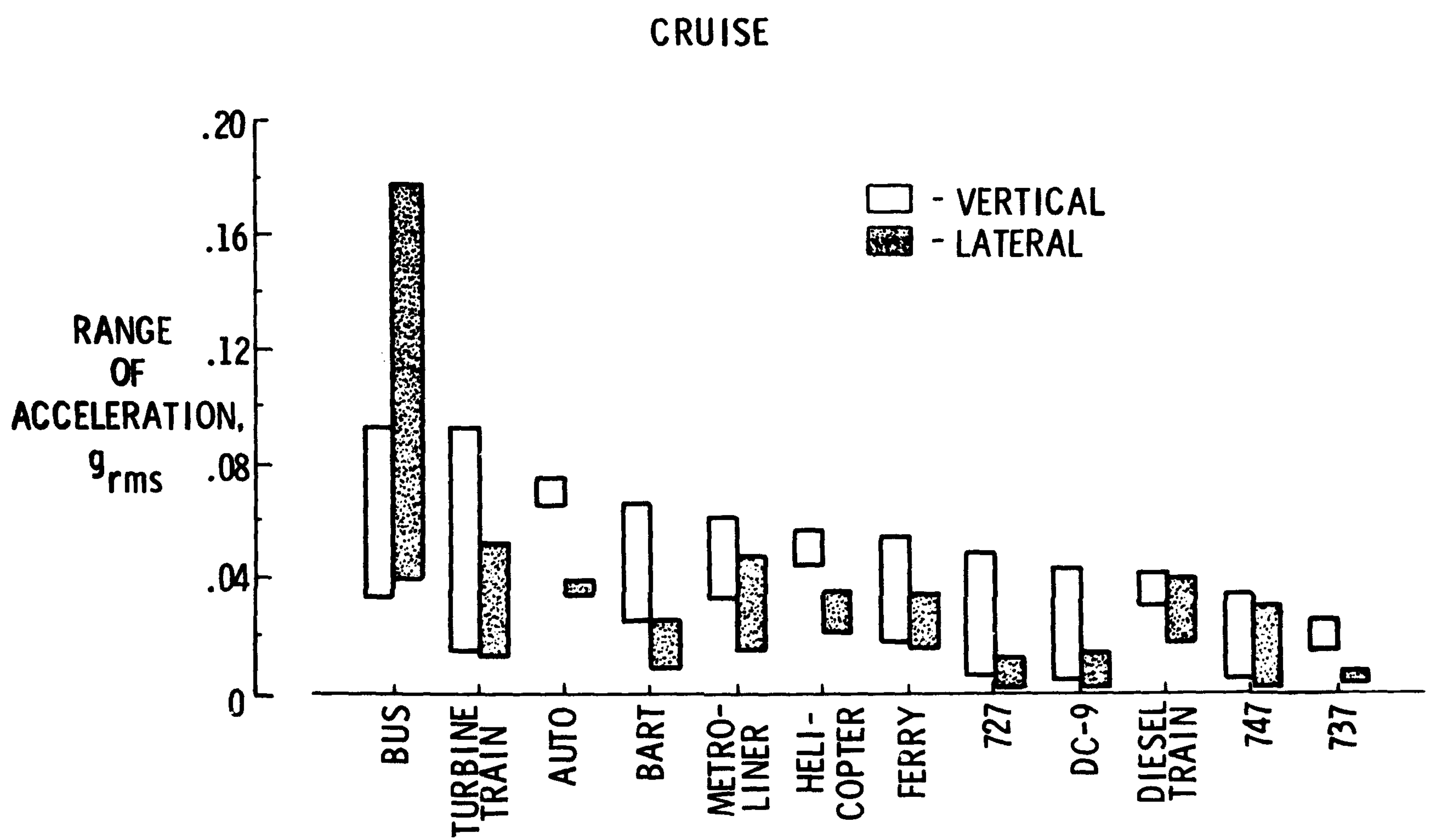

Figure 9.- Comparative data in terms of the overall root-mean-square value of acceleration.

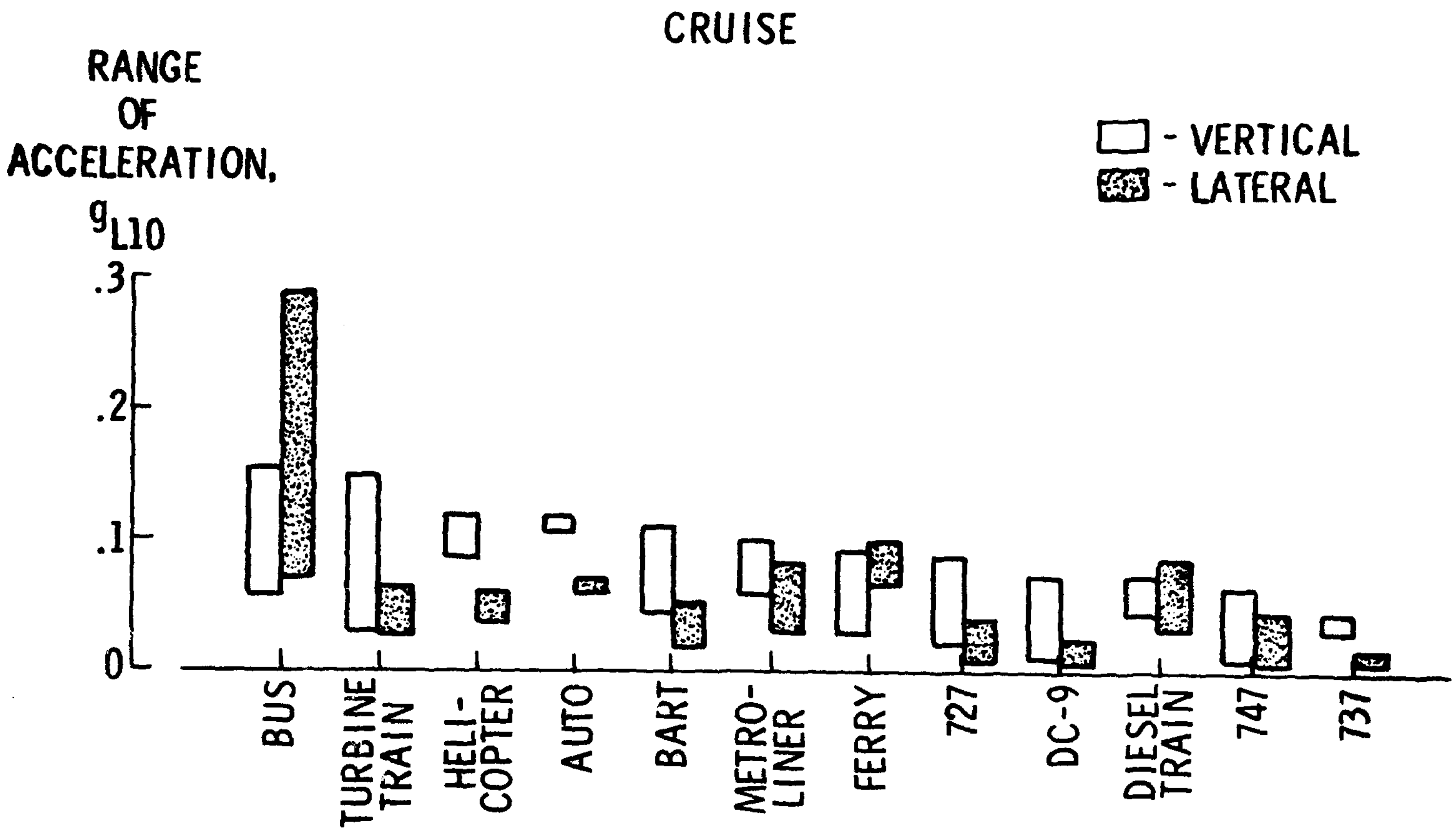

Figure 10.- Comparative data in terms of the vibratory level that is exceeded 10 percent of the time.

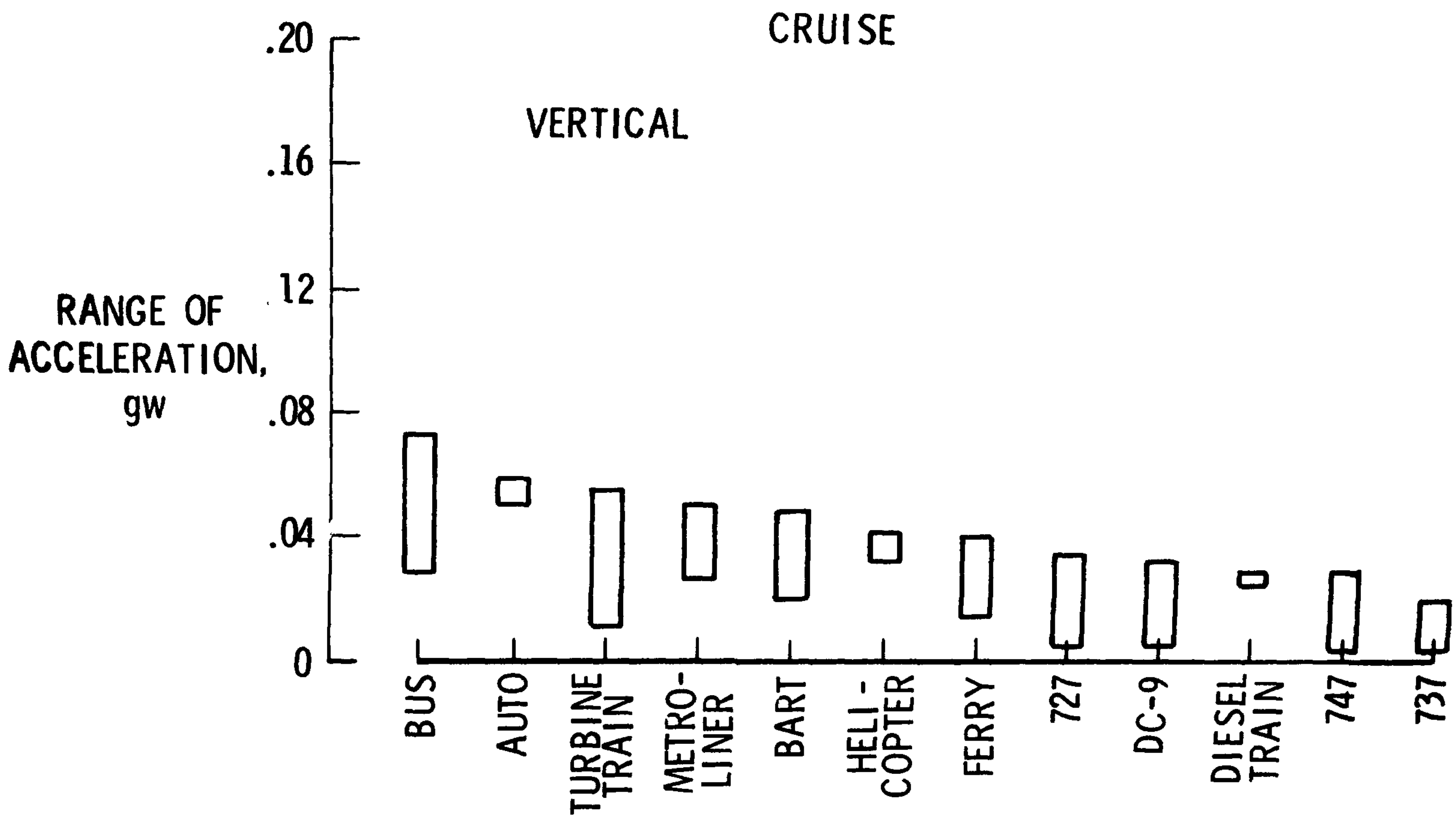

Figure 11.- Comparative data in terms of the weighted root-mean-square value of vertical acceleration.

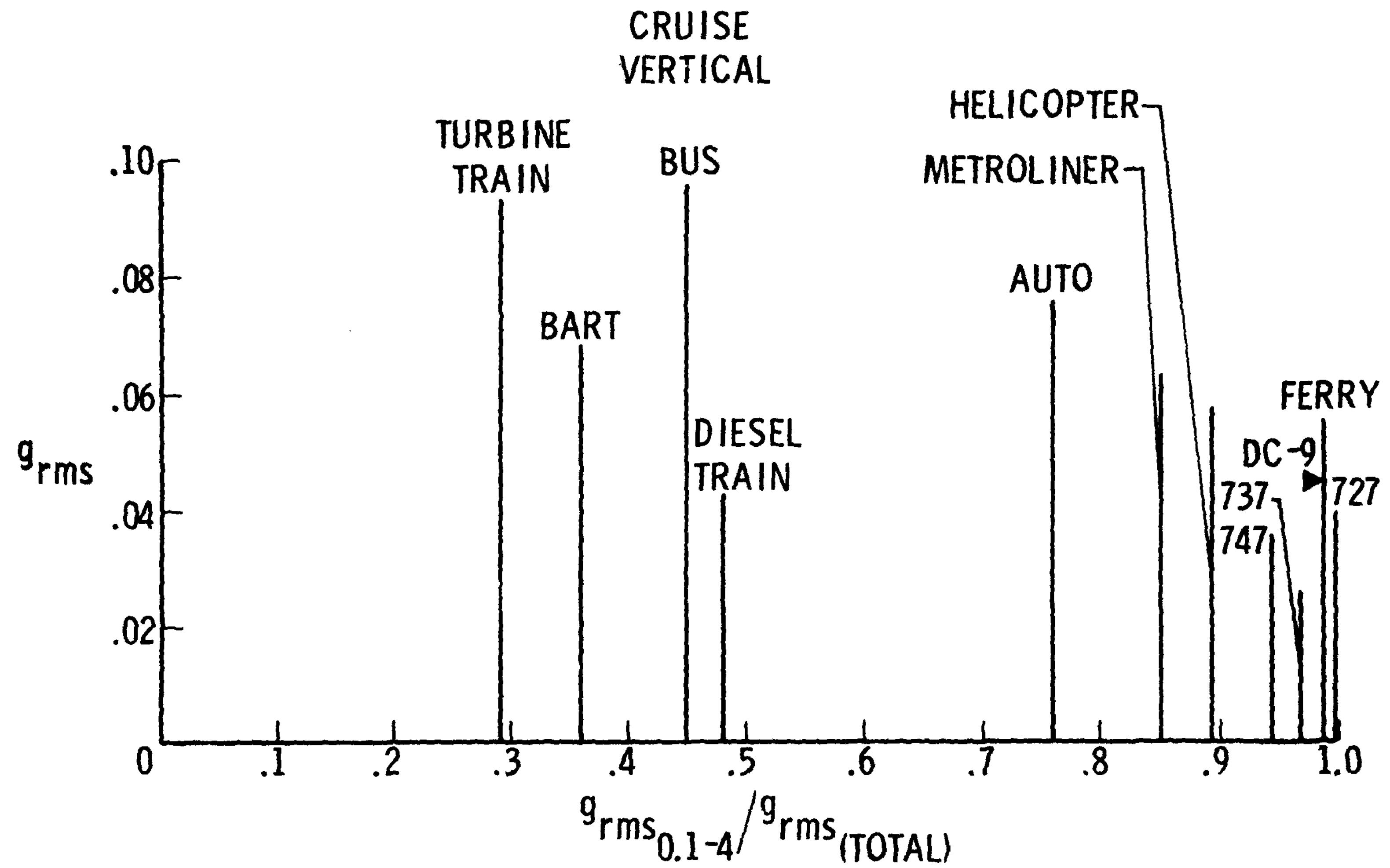

Figure 12.- Comparative vertical acceleration data in terms of frequency bands.

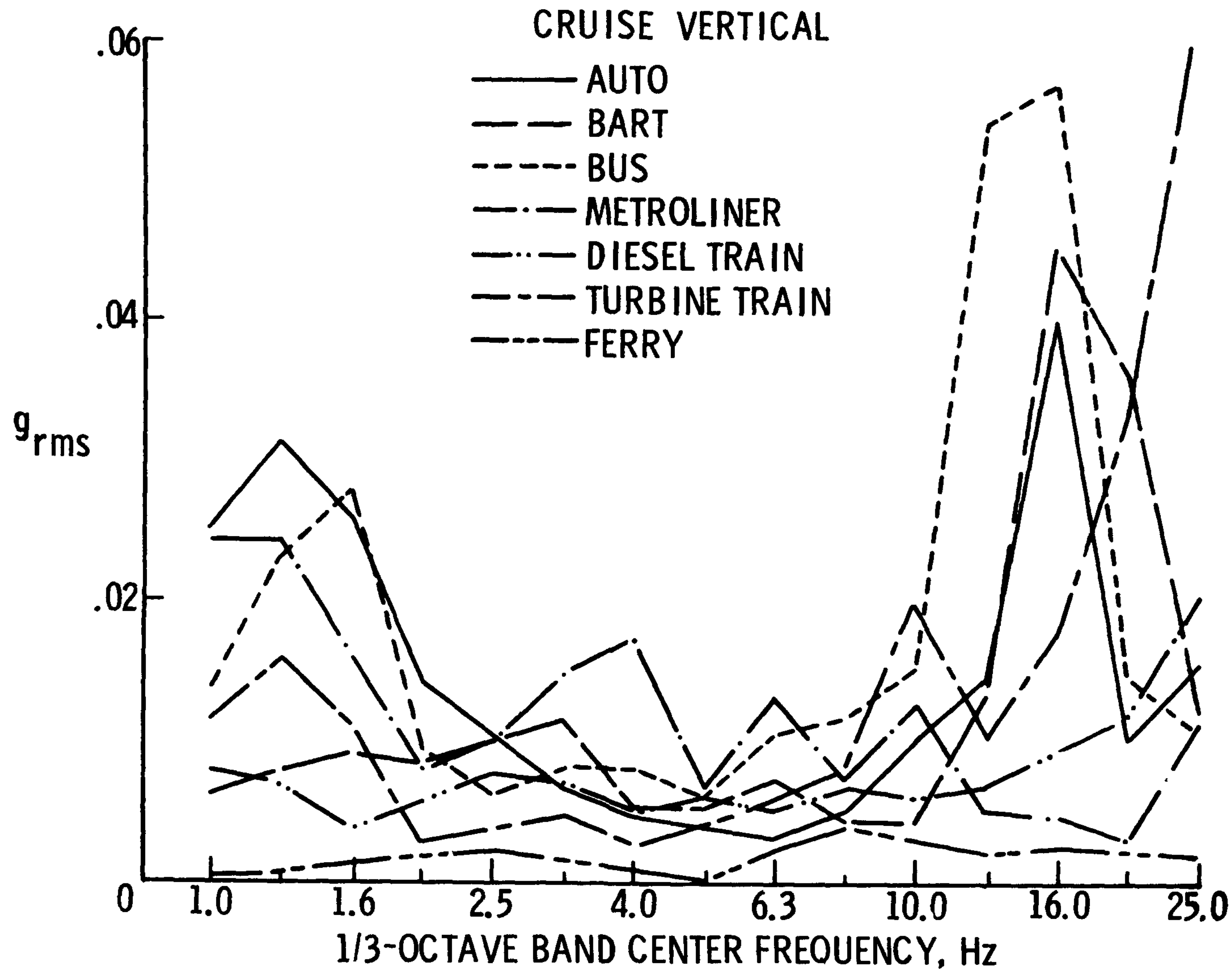

Figure 13.- Comparative vertical acceleration data in terms of 1/3-octave bands.

(a) Surface vehicles.

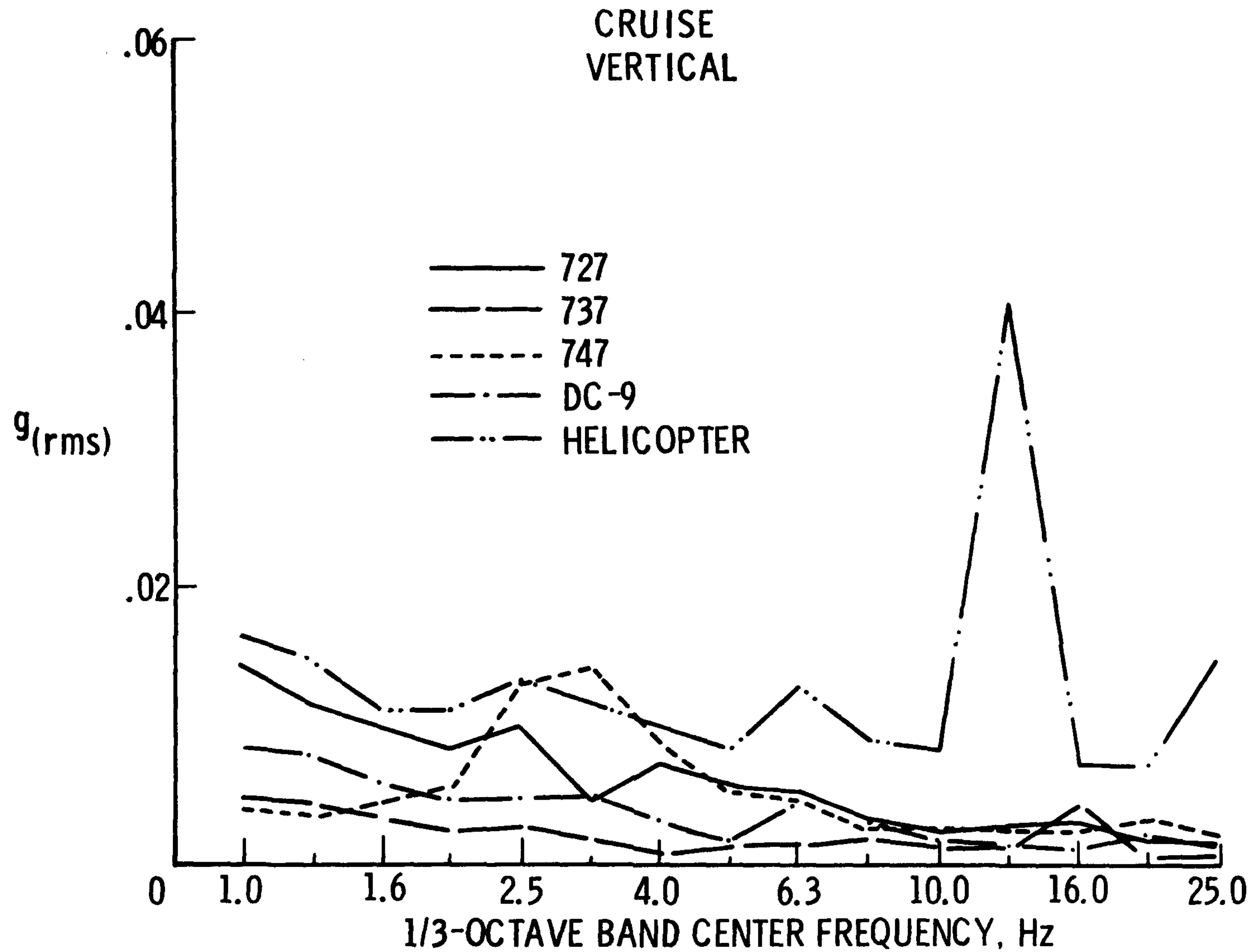

Figure 13.- Concluded.

(b) Aircraft.

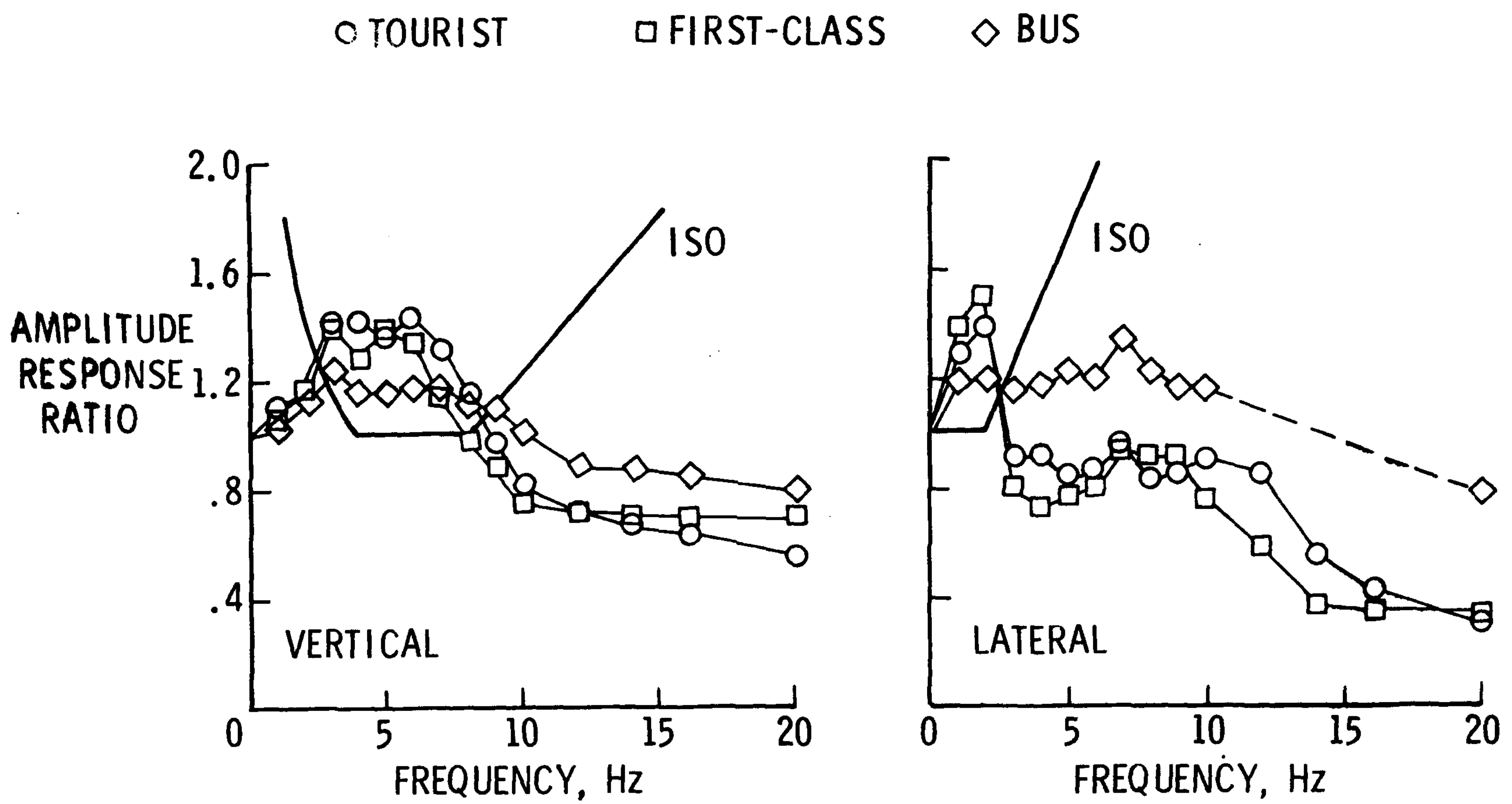

Figure 14.- Seat transmissibility.

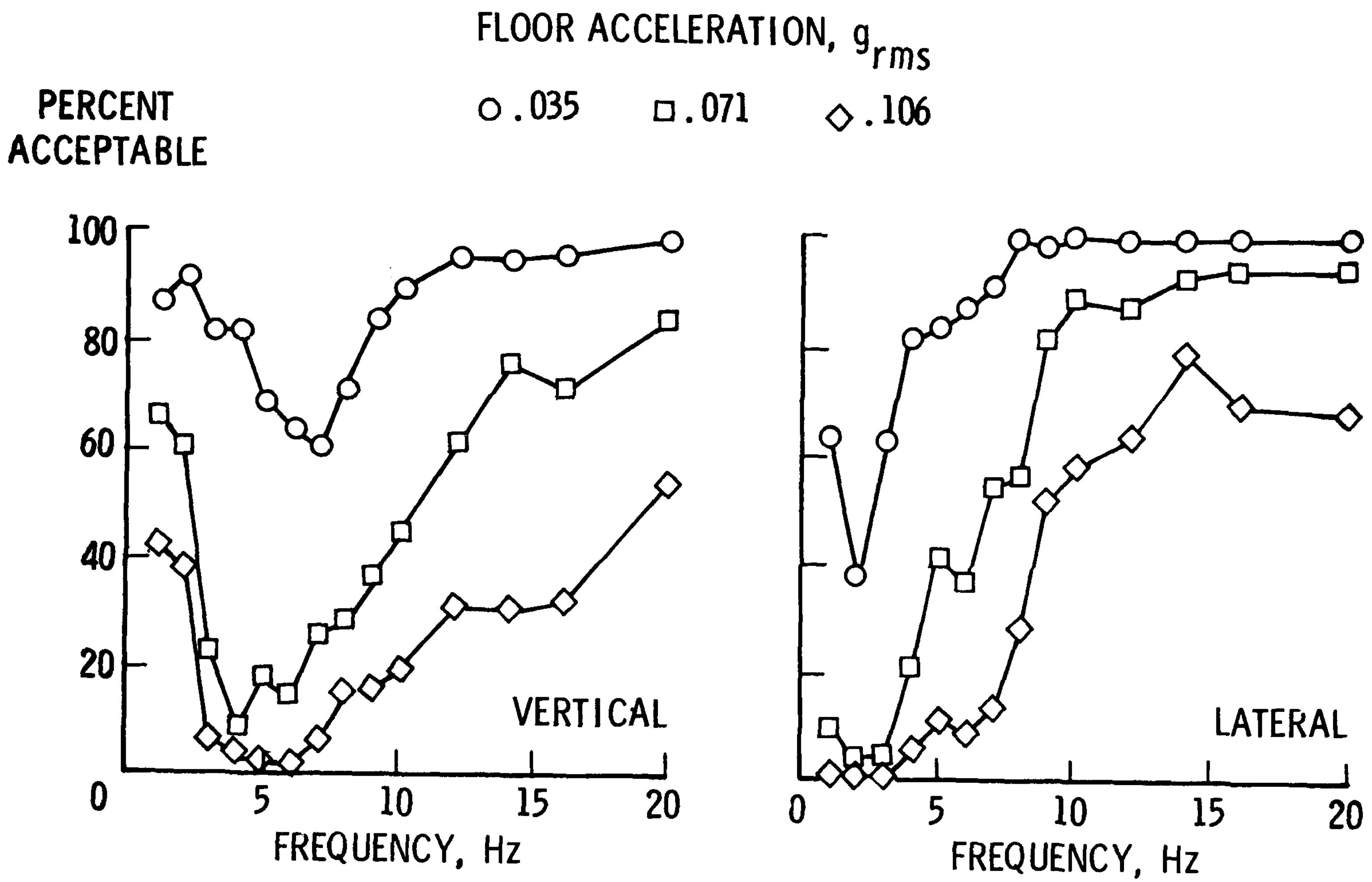

Figure 15.- Passenger acceptability - tourist-class seats.