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VIBRATIONS TRANSMITTED TO HUMAN SUBJECTS THROUGH PASSENGER SEATS AND CONSIDERATIONS OF PASSENGER COMFORT

Jack D. Leatherwood

Langley Research Center
Hampton, Va. 23665

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16. Abstract

An experimental study was conducted to determine the vertical and lateral vibration-transmission characteristics of several types of transport vehicle seats (two aircraft and one bus) to obtain preliminary estimates and comparisons of the ride acceptability of the various seat types. Results of this investigation indicated that from the standpoint of human comfort the seats exhibit undesirable dynamic response characteristics. Amplification of floor vibrations occurred at the frequencies known to be most critical for human comfort in both vertical and lateral axes. An "average" transmissibility function for aircraft seats was tabulated together with the associated variability for use by designers who incorporate similar types of seats in their vehicles. The acceptability of vibrations resulting from floor inputs of 0.10g and 0.15g was low over a broad range of frequencies for both axes and all seat types and was especially low at frequencies where the input was being amplified.

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VIBRATIONS TRANSMITTED TO HUMAN SUBJECTS THROUGH PASSENGER SEATS AND CONSIDERATIONS OF PASSENGER COMFORT

Jack D. Leatherwood
Langley Research Center

SUMMARY

An experimental study was conducted to determine the vibration-transmission characteristics and associated variability of three types of transport vehicle seats (two aircraft and one bus) containing passenger subjects and to obtain preliminary estimates and comparisons of the ride acceptability of the various seat types. The major tool used in this investigation was the multi-degree-of-freedom ride simulator at the Langley Research Center known as the Passenger Ride Quality Apparatus (PRQA). Results of this investigation indicated that the seats either amplify or attenuate the vibration inputs applied at the floor depending upon the frequency of the floor stimuli. Amplification of floor vibrations occurred at the frequencies known to be most critical for human comfort in both vertical and lateral axes. An "average" transmissibility function for aircraft seats was tabulated together with its associated variability for use by designers who incorporate similar types of seats in their vehicles. The acceptability of motions resulting from floor inputs of 0.10g and 0.15g was low over a broad range of frequencies for both axes and all seat types, and was especially low at frequencies where the input was being amplified.

INTRODUCTION

Environmental factors such as vibration, noise, temperature, and so forth, play an important role in the design or improvement of transportation systems. Factors such as these may adversely affect passenger comfort and hence the public acceptability of the transportation system. Future transportation systems such as short take-off and landing (STOL) aircraft and high-speed ground vehicles have the potential to experience more severe vibrations than those encountered in most currently operating systems. As a result, passenger acceptability is expected to become a more important design factor and the compromise between a "good ride" and the vehicle system complexity and cost will take on a more important role in the design process. The question of what constitutes a "good ride" and what vibration levels and frequencies are detrimental to passenger comfort is the subject of an extensive research program now underway at the Langley Research Center.

An excellent summary and comparison of the work done by previous investigators in the area of human sensitivity to whole-body vibration is presented in reference 1. Unfortunately, as pointed out in reference 1, the results of the studies show very little agreement with one another. Among the reasons for such wide disparity in results are differences in the seats used as well as differences in subject sample, rating scale (e.g., polarity, number of scalar points, and adjectives), subject instructions, and differences in experimental design and measurement techniques. A proposal has been made by the International Organization for Standardization (ISO) Committee 108 for an international standard of human vibration exposure limits with respect to safety, performance, and comfort; the committee also proposes to recommend measurement procedures for human whole-body vibration exposure. Discussions of the proposed ISO criteria are given in references 2, 3, and 4 and the actual standard is presented in reference 5. The majority of the previous studies and the proposed criteria have one important factor in common; they are based upon tests conducted with the subjects sitting on rigid seats. All modern passenger transportation systems have some cushioning on the seat and only a very few investigators (see refs. 6 and 7) have obtained subjective ratings and/or measured the seat transmissibility with human subjects seated upon realistic, cushioned seats. Reference 6, for example, presented data to illustrate that the acceleration levels corresponding to the threshold of unpleasantness for pilots was greatly different when measured at the floor as opposed to the acceleration levels calculated to occur at the pilot's spine. The point was made that the establishment of a ride quality criteria for pilots must take into account the transmissibility characteristics of the passenger seat.

In view of the limited data available on seat characteristics this study was undertaken to document the transmissibility characteristics and the passenger acceptability of several typical seat types with the use of a unique and realistic laboratory simulator and a large number (92) of subjects. Such data are especially useful for transportation system designers who can utilize this information in the development of seats and/or suspension systems that will result in improved ride comfort.

The purposes of this paper are: (1) to document the amplitude response characteristics of typical transport vehicle seats; (2) to determine the variability associated with seat amplitude responses; and (3) to make preliminary estimates and comparisons of subjective ride acceptability trends of various seat types for a range of floor vibration amplitude and frequency.

EXPERIMENTAL APPARATUS AND PROCEDURE

Passenger Ride Quality Apparatus

The experimental apparatus utilized in these tests was the Langley Research Center's multi-degree-of-freedom motion simulator called the Passenger Ride Quality Apparatus

(PRQA). A detailed description of the PRQA and its performance characteristics is given in reference 8; only a few of the important features pertinent to this study are described herein. The PRQA is a hydraulically operated system capable of generating single axis motions or combined axis motions in either of two combinations. These combinations are: (1) combined vertical, lateral (side to side), and roll; and (2) combined vertical, longitudinal (fore and aft), and pitch. Inputs to the PRQA can range from discrete frequency sinusoids (or combinations of sinusoids) to actual motions measured on vehicles in operation, such as those described in references 9 and 10 for aircraft and railway vehicles. The system can be controlled manually or by the use of preprogramed magnetic tapes. The basic performance characteristics of the PRQA are summarized in figure 1 (from ref. 8) in terms of the displacement, velocity, and acceleration capabilities of the system for the translational and rotational degrees of freedom.

The research compartment of the PRQA is designed to simulate the upper quarter of a passenger cabin of a modern jet aircraft. An exterior view of the research compartment is presented in figure 2(a) and an interior view of the research compartment with the front bulkhead removed is presented in figure 2(b). The interior view shows the compartment equipped with first class aircraft seats and indicates how closely the interior of the research compartment resembles that of an actual commercial transport. Two other types of seats, aircraft tourist class seats and city rapid-transit bus seats, were also installed in the research compartment for the studies described herein. Photographs of the three seat types are presented in figure 3; table I presents the physical dimensions of each seat.

Accelerometer Installations

The floor of the research compartment contains four servoaccelerometers, three of which measure vertical acceleration directly above each of the three vertical hydraulic actuators which drive the system; the fourth measures the horizontal accelerations at the location of the horizontal actuator. Each individual seat cushion also contained servoaccelerometers for measuring vertical acceleration at the subject-seat interface as indicated in figure 4(a). Servoaccelerometers were used because of their ability to generate large signal outputs at low values of acceleration amplitude and frequency. Figure 4(b) shows the accelerometer installation detail for the seat measurement. As shown, a thin aluminum disk and sleeve arrangement were inserted within the foam cushion material with the flat surface of the disk resting immediately under the seat fabric. The accelerometers were then inserted into the metal sleeve and fixed in place by means of the set screws. As long as the subject remained seated directly on the disk, this arrangement for measuring vertical acceleration proved to be very satisfactory with minimal zero shift caused by variations in the subject posture. Furthermore, the presence of the accelerometers was generally not noticeable to the subjects. The measurement of lateral acceleration proved to be a much more difficult problem since the location(s) of the proper seat-subject interface point(s) at which to measure the vibration stimulus is not clear. Several measurement locations were tried but none proved to be entirely satisfactory. The major difficulties encountered were: (1) zero shifts in the accelerometer output caused by changes in the subject posture; and, (2) local resonances of the accelerometers at their attachment points. These resonances did not occur for the vertical installation arrangement. Consequently, only a sample of lateral data is presented in this paper with the sole purpose of indicating lateral response trends, not absolute response levels. These measurements were made with the accelerometers taped to the front edge of the seat cushions. All accelerometer data were recorded on a strip-chart recorder for quick-look analysis and simultaneously on magnetic tape for detailed analysis.

Subjective ratings were taken with the use of a hand-held box containing push buttons "satisfactory" or "unsatisfactory." The outputs of the six labeled subjective response boxes were commutated onto one channel of the tape recorder and then processed to give oscillograph records showing the rating given by each subject in each seat and for each test condition.

Experimental Procedure

Subjects.- A total of 92 subjects were used in this study. The pertinent subject demographics are listed in table II. Subjects consisted primarily of graduate students, faculty members, and administrative staff members of a local university who had no prior experience in ride quality experiments. The subject breakdown in terms of sex was 48 percent males and 52 percent females.

Instructions.- Upon arriving at the test facility the subjects were taken into a waiting room adjacent to the simulator where they were briefed as to the nature and purpose of the test, the risks involved, the safety features of the system, the details of their participation in the test, and their right to withdraw from the test at their discretion. They were instructed to rate each designated ride segment as "satisfactory" or "unsatisfactory" by pressing corresponding buttons of a subjective response recording box. A complete set of subject instructions is given in appendix A. A copy of the voluntary consent form that each subject was required to sign prior to testing is shown in appendix B. Upon completion of the pretest briefing, the subjects were escorted into the research compartment, seated, and shown the procedure for terminating the tests. At this point the test began.

Test procedure.- The subjects were tested in groups of four, six, and four, corresponding to first class aircraft, tourist class aircraft, and rapid-transit bus seats, respectively. Each group of subjects was exposed to sinusoidal frequencies over the range of 1 to 30 Hz and acceleration amplitudes at the floor of 0.05g, 0.10g, and 0.15g where g denotes the acceleration normalized by the acceleration due to gravity. Each test subject experienced each combination of frequency and floor acceleration a total of 6 (or 4) times (once in each seat) depending upon the particular seat type within which he was being tested. For example, in the tourist class seats each subject experienced all stimuli once in each of the individual tourist seats. In other words, the effect of the seat location was counterbalanced by rotation of the subjects from seat to seat prior to the application of each set of stimuli. The input stimuli were applied manually by the operator of the PRQA who used as the command signal to the system the sinusoidal wave form of a signal generator set at the desired frequency and amplitude. During the application of each individual stimulus, both the floor and seat accelerations were measured as described earlier, and the subjects were asked to rate the quality of the ride of each stimulus as "satisfactory" or "unsatisfactory." A summary of the experimental design used for applying the stimuli is given in tables III(a) and III(b) for the three seat types. Each individual stimulus (i.e., each combined floor acceleration level and frequency) was applied for approximately 10 seconds. The stimuli were presented in groups of three corresponding to the three acceleration levels (0.05g, 0.10g, and 0.15g). A rest period of 10 seconds was allowed before another set of three stimuli was applied at another frequency, with the frequencies being applied in random order.

RESULTS AND DISCUSSION

This experiment was designed to obtain descriptive statistics characterizing the vibration-transmission properties of the three seat types mentioned in the preceding section as well as to measure in a simple manner the overall passenger acceptability of each seat type. The data are described in terms of statistics such as the mean transmissibility ratio, the standard deviation of the transmissibility ratio, the percent of satisfactory ratings, and so forth. The data are presented in two major sections. The first section discusses the vertical and lateral amplitude response characteristics of each seat type and the associated variability of the vertical response data. The second section presents the acceptability rating data obtained for each seat type and includes comparisons of acceptabilities between seat types.

Vertical Transmissibility Characteristics

The vibration response characteristics are presented in this paper in terms of the transmissibility ratio T, which is defined for vertical vibration as the ratio of the peak seat acceleration (acceleration at seat subject interface) to the peak input acceleration at the floor for each discrete input frequency.

Tabulations of the data obtained for the tourist, first class, and bus seats are given in tables IV, V, and VI, respectively. For each combination of frequency and floor acceleration these tables list the mean value of transmissibility, the standard deviation of the transmissibility, the percent of the mean represented by the standard deviation, the maximum value of T (T_{max}), and the minimum value of T (T_{min}).

There were a few values in the T_{max} columns of these tables that exceed 2.0. It was observed during the course of these tests that if a passenger subject slouched in a seat in such a manner that direct contact with the accelerometer mounting disk was lost, then the accelerometer and fixture would register larger outputs because of its unconstrained motion. Such an occurrence resulted in a large value of T. This situation occurred rarely and consequently had minimal effect on the statistical parameters. These large values of T were included in the tables for completeness.

Vertical transmissibility.- The variation of the vertical transmissibility with frequency for the three seat types and a nominal floor acceleration of 0.10g is presented in figures 5(a), 5(b), and 5(c) for tourist class aircraft seats, first class aircraft seats, and bus seats, respectively. The curve on each plot represents the mean transmissibility as averaged over all the individual seats and all subjects for each seat type; the vertical lines represent the 1σ (one standard deviation) variations about the mean transmissibility.

These curves show that on the average for the aircraft seats, the floor accelerations are amplified by a factor of approximately 1.4 over the frequency range of 4 to 8 Hz and are attentuated to a level of about 60 to 70 percent of floor input at frequencies above approximately 9 to 10 Hz. However, for the bus seats, the floor accelerations are amplified by a factor of about 1.2 at the lower frequencies and attenuated at high frequencies to levels of about 70 to 80 percent of floor input. Thus, for a constant level of acceleration input at the floor of the simulator, the amount of acceleration actually transmitted to the subject is highly dependent upon frequency. For example, in the aircraft seats, the seat acceleration experienced by a subject at 5 Hz may be more than twice the acceleration experienced at 30 Hz, even though the floor acceleration levels are identical. Additionally the $\pm\sigma$ points show that the acceleration experienced by the subjects could vary considerably at any particular frequency. For example, at 20 Hz the $\pm\sigma$ curves for the aircraft tourist seats show that transmissibility can vary by a factor of 2.

Another facet to be considered is whether or not tests using deadweights could be utilized to obtain seat response information. Unpublished in-house data using sandbags to simulate passenger loading in the six aircraft tourist class seats indicated that seat responses differed greatly from the data obtained using human test subjects. For the sandbag tests, the peak resonant response of the seats occurred over the same frequency ranges as that obtained using human test subjects. However, the peak transmissibility ratios ranged from a minimum of 2.0 to a maximum of approximately 4.0. For the seats equipped with sandbags, the input acceleration was attenuated to a level of 20 percent of the input at the higher frequencies. Such results indicate that the human subjects act as a very effective but complex damping device, and care should be taken in using data obtained from deadweight tests to approximate human passenger-seat responses.

Variability of vertical transmissibility.- The 1σ points represent the range of T that contains approximately two-thirds of the measured data if the distributions of T are assumed to be normal. An indication of the approximate normality of the data is presented in appendix C where representative samples of the cumulative distributions of the data for a nominal floor acceleration of 0.10g and several frequencies are presented on normal-probability paper. Appendix C shows that the cumulative distributions approximate a straight line, and therefore the assumption or normality is a reasonable one.

The standard deviations of table V for the first class aircraft seats are representative of the variability data as a whole and are presented in figure 6. This plot shows the standard deviation in units of T (nondimensional) corresponding to the three nominal floor acceleration levels as a function of input frequency. The data of figure 6 indicate that the magnitude of the variability of transmissibility ratio does not have a large systematic variation with frequency. However, figure 7 shows that there is a systematic relationship between the percentage of the mean transmissibility represented by each standard deviation (of the transmissibility ratios) and frequency. Figure 7 indicates that as frequency is increased there is an increase in the amount of variability (standard deviation of T) relative to the mean values of T. This implies that at higher frequencies the confidence in any particular measured value of T is less than at the lower frequencies. For example, at frequencies below 4 Hz, the value of the standard deviation ranges from 4 to 16 percent of the mean T; whereas, at frequencies above 15 Hz, the standard deviation is about 25 to 30 percent of the mean T. This means that the percent of error one would expect on the average in measurement of seat transmissibility would be higher at the higher frequencies.

Thus far, the vertical transmissibility data have demonstrated that the stimuli (accelerations) applied at the passenger-seat interface differ appreciably from the stimuli applied at the floor. Furthermore, the variability data show that the stimuli at the passenger-seat interface can be determined only within certain limits of accuracy as defined by the standard deviations.

Comparison of seats.- The mean vertical transmissibility ratios for each seat type and for a floor acceleration level of 0.15g are presented in figure 8. Similar curves were obtained for the other two acceleration levels. The figure also shows the frequency region over which the ISO-reduced comfort curves of reference 5 for vertical vibration take on their minimum values. These data indicate that the mean transmissibility ratios for aircraft seats as compared to bus seats are larger at frequencies below 8 Hz and lower at frequencies above 8 Hz. This relationship is probably caused by the differences in stiffness and damping characteristics of the two basic seat types. Most important, however, the transmissibility ratios for all seats take on their maximum values over the frequency range which is most detrimental to human comfort. This frequency range (3 to 8 Hz) is that at which the major resonances of the human body occur. (See ref. 2, for example.) If the vehicle response has significant energy in the critical frequency region, seat-response characteristics such as those shown in figure 8, have undesirable effects on passenger ride quality. For such vehicles, isolation techniques or redesign of the seat cushioning material could lead to improved seat designs that would minimize the undesirable responses and thus result in improvement of comfort for humans exposed to vertical vibrations.

An important point regarding figure 8 is that the responses of the aircraft tourist and first class seats appear to be very similar. This is borne out by examination of figure 9, which contains all the transmissibility data for the aircraft seats at all levels of input floor acceleration. Since the transmissibility and variability data for the aircraft seats behave in a systematic manner, an "average aircraft seat transmissibility function" for the aircraft seats was computed by averaging the transmissibility data of figure 9 at each frequency. The result is the curve shown in figure 9. Tabulations of the data corresponding to the "average aircraft seat transmissibility function" and the associated standard deviations are given in table VII. Such a function can be used to approximate the effect of seat dynamics in systems with seats that are roughly similar to those described in this discussion. Caution should be used in applying this transmissibility function to distinctly different seat types.

Lateral-Vibration Response Characteristics

An earlier section of this paper ("Apparatus and Instrumentation") discussed the limitations and difficulties of obtaining accurate measurements of lateral seat responses. Because of these problems of measurement, only a few accurate results were obtained. These lateral seat-response data, obtained for <u>individual</u> aircraft first class and tourist class seats, are presented in this section. These data should be interpreted as displaying trends in the lateral seat response and should not be used for obtaining absolute seat-response levels.

The lateral-vibration response data in terms of the transmissibility ratio are presented in figures 10(a) and 10(b) for individual aircraft first class and tourist class seats, respectively. Both figures exhibit the lateral transmissibility ratio as a function of frequency for three nominal levels of horizontal floor acceleration (0.05g, 0.10g, and 0.15g). Also shown in these figures is the frequency range over which the ISO standard (see ref. 5) for lateral vibration takes on its minimum value, corresponding to the range at which people are most sensitive to lateral vibration. These curves show that large seat amplification of floor input occurs at frequencies of 1 to 2 Hz and that this amplification, unfortunately, coincides with the critical frequency range of the ISO standard. Thus, for the two seats discussed herein, the lateral seat-response characteristics are detrimental to passenger comfort. The major observed effect upon the passenger was large motions of the head and body trunk. At the higher frequencies the lateral input accelerations were attenuated to levels as low as 40 percent of the input, and very little motion of the passenger subjects could be detected by visual observation.

Passenger Ride Acceptance

Vertical motion acceptance.- Passenger acceptability for these tests was measured with the use of a simple binary rating scale. For each test condition the subjects were asked to rate the quality of the ride as being either satisfactory or unsatisfactory. The results were tabulated and used to calculate a parameter called the acceptance fraction AF, which is defined as the fraction of subjects at each stimulus condition who rated the ride as satisfactory. For purposes of illustration, AF = 1.0 means that all subjects rated a ride as satisfactory; AF = 0 means that none of the subjects rated a ride as satisfactory, and an intermediate value such as AF = 0.20 means that 20 percent of the subjects were satisfied with the ride. Figure 11(a) displays the acceptance fraction obtained with aircraft tourist class seats as a function of frequency for each level of floor acceleration. Figures 11(b) and 11(c) present the acceptance fractions for aircraft first class seats and bus seats, respectively. Figure 11 shows that the acceptance fraction for each floor acceleration level is markedly lower in the frequency range of 4 to 9 Hz than at other frequencies. These frequencies are associated not only with the major body resonances (see refs. 1 and 2) but also with the magnification of acceleration at the seat. (See fig. 5.) The data of each figure also show distinct differences in the acceptance fraction for the three levels of floor acceleration. For all frequencies, an increase of input acceleration level results in a marked decrease in the acceptance fraction.

Lateral motion acceptance.- The acceptance fractions obtained for lateral vibrations are presented in figure 12 as a function of input frequency and floor acceleration level. These curves display very small acceptance fractions (dips in the curves) at frequencies of 2 to 5 Hz for all seats, with lesser reductions in the acceptance fraction at frequencies between 10 and 15 Hz. The very small acceptance fractions at the lower frequencies correspond to the frequency range over which lateral inputs are amplified and the passengers experience great discomfort caused by the pronounced head and body-trunk motions. The reason for the dips at the higher frequencies (noted on bus and first class seats) is unclear. These data also show distinct differences in the acceptance fraction as a function of lateral floor acceleration (i.e., decreasing acceptance fraction for increases in lateral floor input). Of particular note is the fact that for a lateral floor input acceleration of 0.15g the acceptance fraction is generally zero for frequencies below 4 Hz.

Comparison of vertical and lateral acceptance.- The data of the previous section suggest that lateral vibrations are less acceptable than vertical vibrations at the lower frequencies. This can be demonstrated by comparing a selected pair of curves from figures 11 and 12. Such a comparison of the vertical and lateral acceptance fractions for tourist class seats at a floor acceleration input level of 0.10g is given in figure 13 and is typical of the results obtained for the other seats and floor input conditions. The results shown in figure 13 indicate that for frequencies equal to or below 3 Hz the vertical vibrations are more acceptable than lateral vibrations; whereas, above 3 Hz the lateral motions become the most acceptable. These data support the proposed ISO standards for vertical and lateral sinusoidal vibration. In fact, the ISO standards for vertical and lateral reduced-comfort boundaries have their crossover at about 3.15 Hz. The fact that these results were obtained using cushioned seats and are in agreement with the ISO, standards which are based on rigid seat tests, indicates that seat transmissibility did not affect the basic trends associated with passenger acceptance in the two axes of interest.

Comparison of seat types.- The acceptance fractions in the vertical axis for the three types of seats used in this study are shown in figure 14 for a floor acceleration input level of 0.10g. An inspection of this figure reveals that over the frequency range of 3 to 8 Hz the bus seats were slightly more acceptable than the aircraft seats and at the higher frequencies the bus seats became less acceptable. This could result from the fact that the aircraft seats are softer than the bus seats and amplify more of the floor vibration over the critical frequency region and less at the higher frequencies. In terms of lateral acceptability, the seat comparison curves for a floor acceleration of 0.10g are presented in figure 15. Here differences between seat types become more readily apparent at frequencies greater than about 15 Hz, as indicated by the spread in the acceptance fraction curves. The bus seats are least acceptable at the higher frequencies, the first class aircraft seats more acceptable, and the tourist class seats the most acceptable. These differences in acceptability may be caused by the basic differences in seat geometry as indicated in table I and figure 4. The bus seats have no armrests, and thus the subjects have no means of restraining the tendency of the body trunk to rotate about the seat surface, a tendency which would logically cause the most discomfort. The first class and tourist class seats have armrests which provide a means for subjects to reduce either consciously or unconsciously the rocking motions caused by lateral vibrations. The width between the armrests for tourist class seats is less than the width on first class seats. The lesser width provides the subjects the most efficient means of countering the rocking motions and improving their comfort.

CONCLUDING REMARKS

An experimental study has been conducted to determine the amplitude response characteristics and subjective acceptability of typical transport vehicle seats over a wide range of frequency (1 to 30 Hz) and floor acceleration amplitudes (0.05g, 0.10g, and 0.15g). The seat types investigated were aircraft tourist class seats, aircraft first class seats, and rapid-transit bus seats. Comparisons of seat responses and passenger acceptability were made between seat types as well as with the ISO standards. An "average aircraft seat transfer function" was generated for use in systems incorporating aircraft type seats.

All three seat types exhibited vibration response characteristics in both the vertical and lateral axes consisting of amplification of the floor vibration over the frequency ranges (3 to 8 Hz for vertical and 1 to 2 Hz for lateral) known to be the most critical or uncomfortable for passenger subjects. Vertical transmissibility ratios varied from an average of 1.4 for aircraft seats to a value of 1.2 for bus seats. These results were very different from unpublished in-house tests where the human subjects were approximated by deadweights (sandbags) indicating that human subjects act as effective, but complex, damping systems when seated on realistic cushioned seats. The variability associated with the transmissibility ratios for each seat type was large (as much as 30 to 40 percent of mean transmissibility at the higher frequencies) and probably is a function of such factors as subject weight, subject posture, differences in individual seat cushions, and so forth. A redesign of seat cushioning materials in order to add damping and stiffness might alter the seat-response characteristics and improve the ride quality at a relatively minor expense.

Comparisons of vertical transmissibility between the three seat types indicated that the two aircraft seat types gave similar responses over the amplitude and frequency range studied; as a result, an "average aircraft seat transmissibility function" was computed with the associated standard deviation. This transmissibility function can be used by designers for estimating seat dynamics of transportation systems with similar seat types.

The acceptability of vertical vibrations was especially low in the frequency range of 4 to 9 Hz for all levels of floor input acceleration. These frequencies are those associated with the major body resonances as well as with the magnification of acceleration at the seat. The acceptability of lateral vibrations was very low in the 2- to 5-Hz frequency region which also corresponded to the frequencies at which the seats amplified floor acceleration. Comparisons of vertical and lateral acceptability data showed a crossover effect at approximately 3 Hz. Below 3 Hz lateral vibrations were less acceptable than vertical vibrations; above 3 Hz they became the most acceptable. These data support the ISO standard.

Comparisons of passenger acceptability of the three seat types for vertical vibration indicated only slight differences in acceptability. For lateral vibrations at the higher frequencies (above 15 Hz), the acceptability of the various seats was distinctly different and probably attributable to seat geometry and restraint mechanisms, i.e., lack of armrests for bus seats.

Langley Research Center,
National Aeronautics and Space Administration,
Hampton, Va., March 31, 1975.

APPENDIX A

SUBJECT INSTRUCTIONS

You have volunteered to participate in a research program to investigate the quality of ride, or comfort, associated with various transportation systems such as aircraft, trains, and buses. Specifically, we wish to identify the types of motion or vibration which most influence a person's sense of well-being or comfort. To do this we have built an aircraft simulator which can expose passengers to realistic ride motions in one or more directions at one time. The system has been designed to meet stringent safety requirements such that it cannot expose subjects to motions which are known to cause injury. It contains many built-in safety features which automatically shut the system down if it does not perform properly.

The test that you will participate in today is being conducted to determine how much vibration is transmitted from the floor of the aircraft through the seat cushion itself. The seat cushions have been instrumented to measure the transmitted vibrations. You will enter the aircraft, take a seat, fasten the seat belt, and assume a comfortable position with both feet on the floor. Selected vibrations will then be applied to the cabin. You are to make yourself as comfortable and relaxed as possible while the test is being conducted. You must, however, keep your seatbelts fastened at all times. During the tests you will be in continuous two-way communication with the test conductor.

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

During the test there will be motions that we want you to rate as either "satisfactory" or "unsatisfactory." These motions will come in segments about 10 seconds long. At the beginning of each segment you are to rate, the test conductor will say "start," and at the end of the segment, he will say "stop." You will be provided a small black box with five push buttons with which to record your rating. If the quality of the ride segment is satisfactory to you, press the button numbered "one." If the quality is not satisfactory to you, press the button numbered "two." You are to press the appropriate button immediately after you hear the word "stop" signifying the end of the segment. Please do not be concerned about whether your ratings agree with the others in the aircraft with you. Remember, we want to know how <u>different</u> people feel about the ride. You may talk between segments you are to rate but please do not talk during them. Are there any questions about what you are to do?

Upon entering the simulator, the subject should be told: "Please be seated and fasten your seat belt." (Wait until all the subjects are ready.) "Now, the mirror you see in front of you is a one-way mirror, and as I told you before, the test conductor will be able to hear everything you say. Also, if you wish to end the test, you can undo your seat belt, press one of these little buttons (point to both), or you can ask the test conductor to stop the test and let you out. This first test will take about a half hour."

APPENDIX B

VOLUNTARY CONSENT FORM FOR PASSENGERS ON THE PASSENGER RIDE QUALITY APPARATUS

I understand the purpose of the research and the techniques to be used, including my participation in the research, as explained to me by the Principal Investigator (or qualified designee).

I do voluntarily consent to participate as a subject in the Passenger Ride Quality Apparatus experiment to be conducted at NASA Langley Research Center on ________________.
(Date)

I understand that I may at any time withdraw from the experiment and that I am under no obligation to give reasons for withdrawal or to attend again for experimentation.

I undertake to obey the regulations of the laboratory and instructions of the Principal Investigator regarding safety, subject only to my right to withdraw declared above.

I affirm that, to my knowledge, my state of health has not changed since the time at which I completed and signed the medical report form required for my participation as a test subject.

____
(Signature of Subject)

APPENDIX C

NORMALITY CONSIDERATIONS

The cumulative probability distributions of the seat-response data were computed for all three seat types at each frequency-input amplitude combination. The results indicated that the seat-response data were approximately normal for all seats and input test conditions. Sample cumulative distributions of transmissibility ratio for tourist class aircraft seats at a floor acceleration level of 0.10g are presented in figures 16(a) to 16(g) for several values of input frequency. The transmissibility ratio data range for each frequency was divided into 20 cells and the value of the transmissibility ratio corresponding to the first cell of each plot is listed on the plot together with the cell width used. Thus, to obtain the value of transmissibility ratio at any cell number use the following formula:

$$T_n = C_1 + (n - 1)\Delta C$$

where

T_n	transmissibility ratio at cell n, nondimensional
C_1	value of cell 1, nondimensional
n	cell number, nondimensional
ΔC	cell width, nondimensional

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9. Conner, D. William: Ride Quality – An Increasingly Important Factor in Transportation Systems. Paper presented at 1971 International IEEE Conference on Systems, Networks, and Computers (Oaxtepec, Mexico), Jan. 1971.

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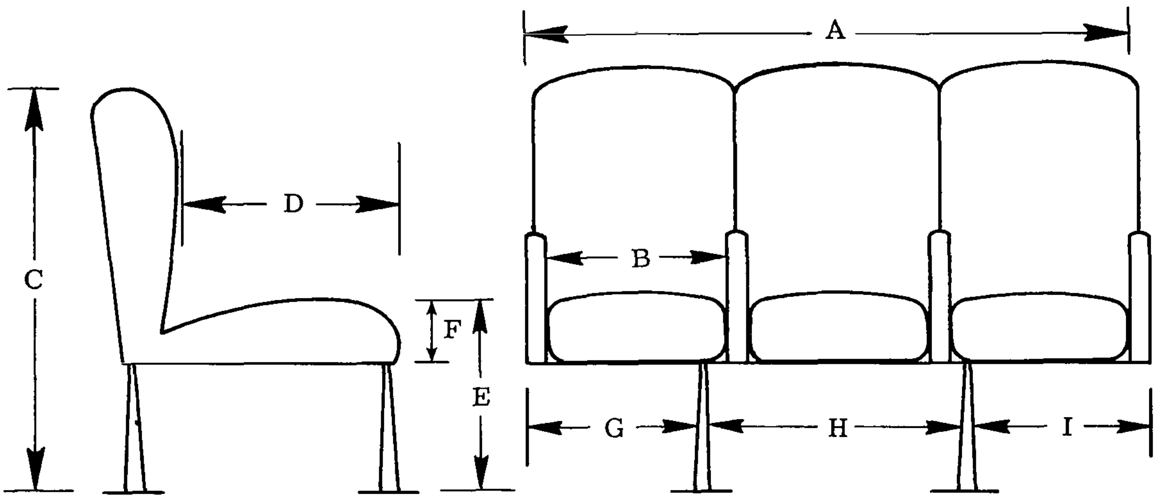
TABLE I.- SEAT DIMENSIONS



Seat type	Dimensions, m (in.), for –								
	A	B	C	D	E	F	G	H	I
Tourist	1.50 (59.2)	0.44 (17.5)	1.03 (40.5)	0.47 (18.5)	0.46 (18)	0.06 (2.5)	0.46 (18)	0.53 (21)	0.43 (17)
First class	1.50 (59.0)	0.52 (20.5)	1.09 (43.0)	0.48 (19.0)	0.46 (18)	0.10 (4.0)	0.53 (21)	0.53 (21)	0.36 (14)
Bus	0.88 (34.5)	(a) ---	0.90 (35.5)	0.43 (17.0)	0.46 (18)	0.10 (4.0)	0.18 (7)	0.53 (21)	0.18 (7)

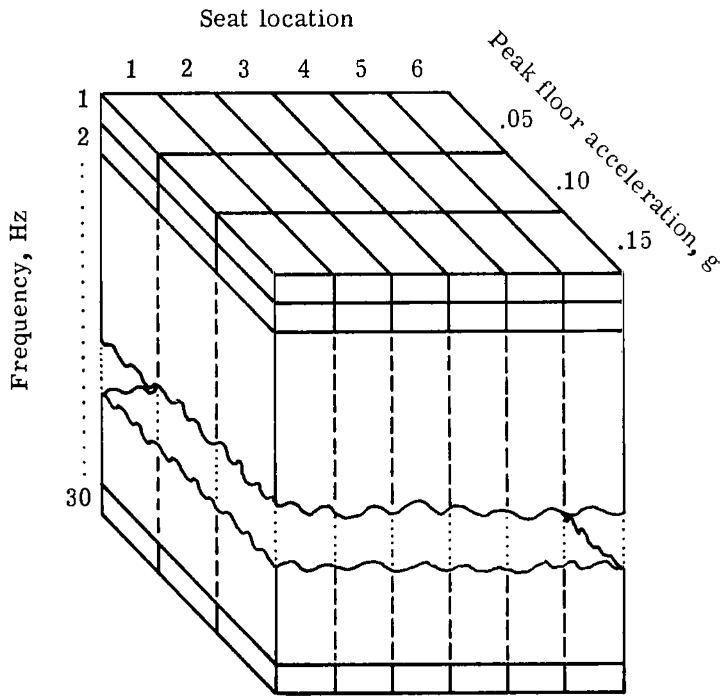
[a]No armrests.

TABLE II.- SUBJECT AGE AND WEIGHT DEMOGRAPHICS

Seat type	For tests in the direction of –						Age		
	Vertical			Lateral					
	Number of subjects	Average weight	Standard deviation	Number of subjects	Average weight	Standard deviation	Median age	Minimum age	Maximum age
Tourist	24	157	38	24	149	39	22.0	19	32
First class	12	147	31	8	144	40	23.5	18	49
Bus	12	140	40.9	12	141	28	22.5	18	46
Overall totals	48	---	---	44	---	---	---	---	---

TABLE III.- BASIC EXPERIMENTAL DESIGN

(a) Tourist class aircraft seats.



(b) First class aircraft and bus seats.

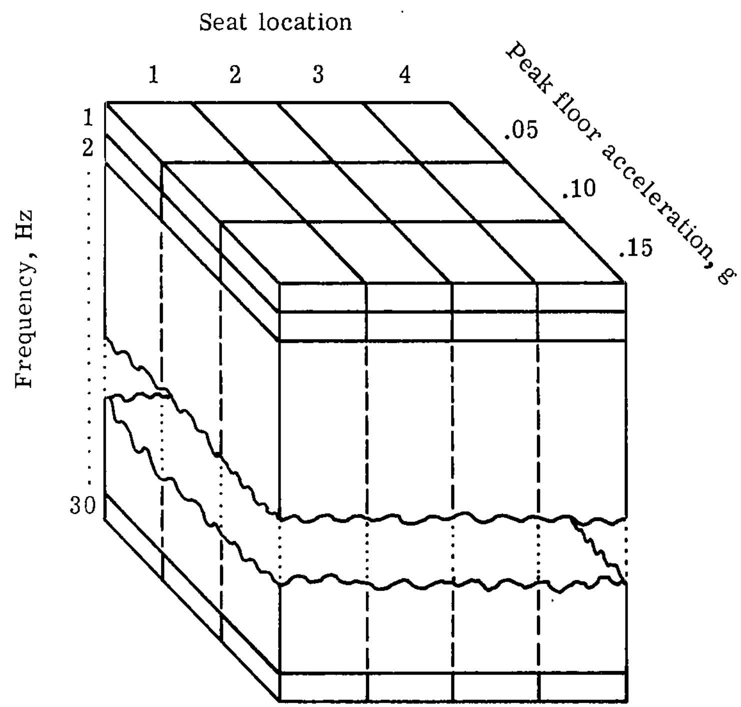


TABLE IV.- STATISTICAL RESPONSE DATA FOR TOURIST CLASS AIRCRAFT SEATS

Frequency, Hz	Floor acceleration, 0.05g					Floor acceleration, 0.10g					Floor acceleration, 0.15g				
	Transmissibility					Transmissibility					Transmissibility				
	Mean[a]	σ[b]	Percent mean[c]	T_{max}	T_{min}	Mean	σ	Percent mean	T_{max}	T_{min}	Mean	σ	Percent mean	T_{max}	T_{min}
1	1.167	0.125	10.7	1.54	0.88	1.089	0.068	6.2	1.22	0.95	1.088	0.098	9.0	1.33	0.91
2	1.146	.117	10.2	1.36	.84	1.196	.072	6.0	1.40	1.01	1.167	.058	5.0	1.23	1.08
3	1.057	.150	14.2	1.36	.82	1.366	.072	5.3	1.66	1.25	1.409	.109	7.7	1.75	1.24
4	1.266	.188	14.8	1.76	.90	1.465	.174	12.0	1.98	1.15	1.409	.177	12.6	1.79	1.03
5	1.288	.204	15.8	1.80	.80	1.418	.180	12.7	1.89	1.08	1.356	.245	18.1	1.83	1.03
6	1.224	.193	15.8	2.00	.88	1.450	.211	14.6	1.95	1.12	1.428	.174	12.2	1.88	1.09
7	1.304	.207	15.9	2.00	1.00	1.374	.153	11.1	1.82	1.04	1.308	.145	11.1	1.67	1.02
8	1.281	.342	26.7	2.52	.92	1.228	.164	12.7	1.48	.99	1.130	.205	18.1	1.35	.86
9	1.043	.223	21.4	1.84	.66	1.004	.143	14.2	1.31	.77	.962	.132	13.7	1.37	.72
10	.822	.143	17.4	1.44	.62	.812	.108	13.3	1.04	.58	.805	.112	13.9	1.03	.57
12	.756	.249	32.9	1.76	.40	.697	.156	22.4	1.16	.26	.714	.154	21.6	1.24	.39
14	.695	.244	35.1	1.84	.36	.645	.132	20.5	1.04	.41	.661	.123	18.6	.92	.43
16	.648	.221	34.1	1.92	.30	.626	.148	23.6	1.06	.37	.638	.146	22.9	1.00	.39
20	.610	.245	40.2	1.76	.26	.582	.203	34.9	1.22	.28	.554	.180	32.5	1.08	.24
25	.556	.185	33.3	1.04	.24	.557	.183	32.8	1.04	.20	.557	.172	30.9	1.00	.19
30	.483	.147	30.4	.88	.20	.552	.173	31.3	.98	.15	.518	.169	32.6	1.00	.12

[a] Computed from 72 data points.

[b] σ is standard deviation of T (nondimensional).

[c] Percent mean = $\sigma/\overline{T} \times 100$ = Percent of mean T represented by σ.

TABLE V.- STATISTICAL RESPONSE DATA FOR FIRST CLASS AIRCRAFT SEATS

Frequency, Hz	Floor acceleration, 0.05g					Floor acceleration, 0.10g					Floor acceleration, 0.15g				
	Transmissibility					Transmissibility					Transmissibility				
	Mean[a]	σ[b]	Percent mean[c]	T_{max}	T_{min}	Mean	σ	Percent mean	T_{max}	T_{min}	Mean	σ	Percent mean	T_{max}	T_{min}
1	1.077	0.165	15.3	1.32	0.72	1.120	0.134	12.0	1.44	1.00	1.058	0.068	6.4	1.25	0.92
2	1.068	.157	14.7	1.28	.76	1.200	.051	4.2	1.28	1.08	1.153	.061	5.3	1.28	1.04
3	1.069	.172	16.1	1.40	.80	1.410	.118	8.4	1.72	1.20	1.387	.132	9.5	1.97	1.14
4	1.266	.094	7.4	1.48	1.00	1.419	.206	14.5	2.00	1.10	1.273	.144	11.3	1.60	1.00
5	1.276	.156	12.2	1.64	.88	1.384	.182	13.2	1.84	1.00	1.379	.188	13.6	1.85	1.07
6	1.238	.150	12.1	1.60	.96	1.388	.190	13.7	1.76	.96	1.324	.174	13.1	1.84	.99
7	1.274	.180	14.1	1.64	.88	1.305	.162	12.4	1.72	1.00	1.133	.122	10.8	1.44	.91
8	1.166	.185	15.9	1.56	.80	1.103	.152	13.8	1.52	.88	.978	.124	12.7	1.26	.80
9	.983	.127	12.9	1.28	.80	.942	.138	14.6	1.36	.68	.874	.107	12.2	1.20	.72
10	.864	.109	12.6	1.04	.60	.763	.092	12.0	.96	.60	.752	.092	12.2	1.02	.64
12	.748	.118	15.8	1.20	.56	.703	.088	12.5	.82	.48	.706	.085	12.0	.93	.48
14	.695	.134	19.2	.96	.48	.677	.095	14.0	.88	.48	.697	.117	16.8	.92	.52
16	.732	.162	22.1	1.20	.48	.686	.121	17.6	1.00	.44	.689	.119	17.3	1.00	.47
20	.696	.242	34.8	1.12	.32	.728	.187	25.7	1.08	.40	.693	.154	22.2	1.10	.32
25	.586	.171	29.2	1.16	.32	.643	.174	27.1	1.08	.32	.636	.163	25.6	1.05	.36
30	.585	.155	26.5	.88	.36	.586	.161	27.5	.94	.24	.600	.172	28.7	1.05	.27

[a] Computed from 40 data points.

[b] σ is standard deviation of T (nondimensional).

[c] Percent mean = $\sigma/\overline{T} \times 100$ = Percent of mean T represented by σ.

TABLE VI.- STATISTICAL RESPONSE DATA FOR BUS SEATS

Frequency, Hz	Floor acceleration, 0.05g					Floor acceleration, 0.10g					Floor acceleration, 0.15g				
	Transmissibility					Transmissibility					Transmissibility				
	Mean[a]	σ[b]	Percent mean[c]	T_{max}	T_{min}	Mean	σ	Percent mean	T_{max}	T_{min}	Mean	σ	Percent mean	T_{max}	T_{min}
1	1.076	0.079	7.3	1.28	0.88	1.136	0.090	7.9	1.24	0.96	1.019	0.045	4.4	1.07	0.93
2	.948	.093	9.8	1.12	.80	1.153	.089	7.7	1.32	1.04	1.110	.059	5.3	1.23	.96
3	.951	.066	6.9	1.12	.80	1.204	.098	8.1	1.44	1.04	1.229	.049	4.0	1.31	1.11
4	1.085	.100	9.2	1.28	.88	1.242	.169	13.6	1.68	.96	1.146	.080	7.0	1.31	.96
5	1.035	.112	10.8	1.32	.86	1.049	.104	9.9	1.28	.84	1.148	.089	7.8	1.37	.91
6	.948	.124	13.1	1.24	.64	1.152	.157	13.6	1.52	.84	1.162	.119	10.2	1.41	.93
7	1.016	.129	12.7	1.28	.72	1.203	.149	12.4	1.52	.88	1.159	.116	10.0	1.40	.91
8	1.020	.160	15.7	1.54	.72	1.151	.153	13.3	1.68	.98	1.109	.142	12.8	1.42	.87
9	1.030	.162	15.7	1.54	.80	1.094	.188	17.2	1.56	.44	1.091	.134	12.3	1.42	.85
10	.851	.133	15.6	1.20	.64	.998	.150	15.0	1.44	.72	1.003	.144	14.4	1.40	.75
12	.798	.136	17.0	1.24	.56	.868	.156	18.0	1.22	.54	.879	.144	16.4	1.25	.56
14	.688	.117	17.0	.92	.40	.841	.139	16.5	1.16	.56	.864	.164	19.0	1.20	.51
16	.603	.124	20.6	.88	.40	.791	.147	18.6	1.16	.50	.850	.157	18.5	1.28	.53
20	.648	.102	15.7	.80	.32	.757	.133	17.6	1.24	.52	.798	.158	19.8	1.23	.45
25	.598	.129	21.6	.88	.32	.791	.152	19.2	1.16	.52	.827	.180	21.8	1.23	.48
30	.531	.120	22.6	.88	.32	.669	.148	22.1	1.12	.36	.723	.150	20.8	1.07	.45

[a] Computed from 48 data points.

[b] σ is standard deviation of T (nondimensional).

[c] Percent mean = $\sigma/\overline{T} \times 100$ = Percent of mean T represented by σ.

TABLE VII.- AVERAGE TRANSMISSIBILITY RATIO AND ASSOCIATED STANDARD DEVIATION FOR AIRCRAFT SEATS

Floor input frequency	Average transmissibility ratio	Standard deviation
1	1.100	0.110
2	1.155	.091
3	1.283	.124
4	1.350	.170
5	1.350	.198
6	1.374	.185
7	1.283	.164
8	1.115	.216
9	.968	.155
10	.803	.113
12	.721	.163
14	.678	.156
16	.670	.161
20	.644	.205
25	.589	.175
30	.554	.162

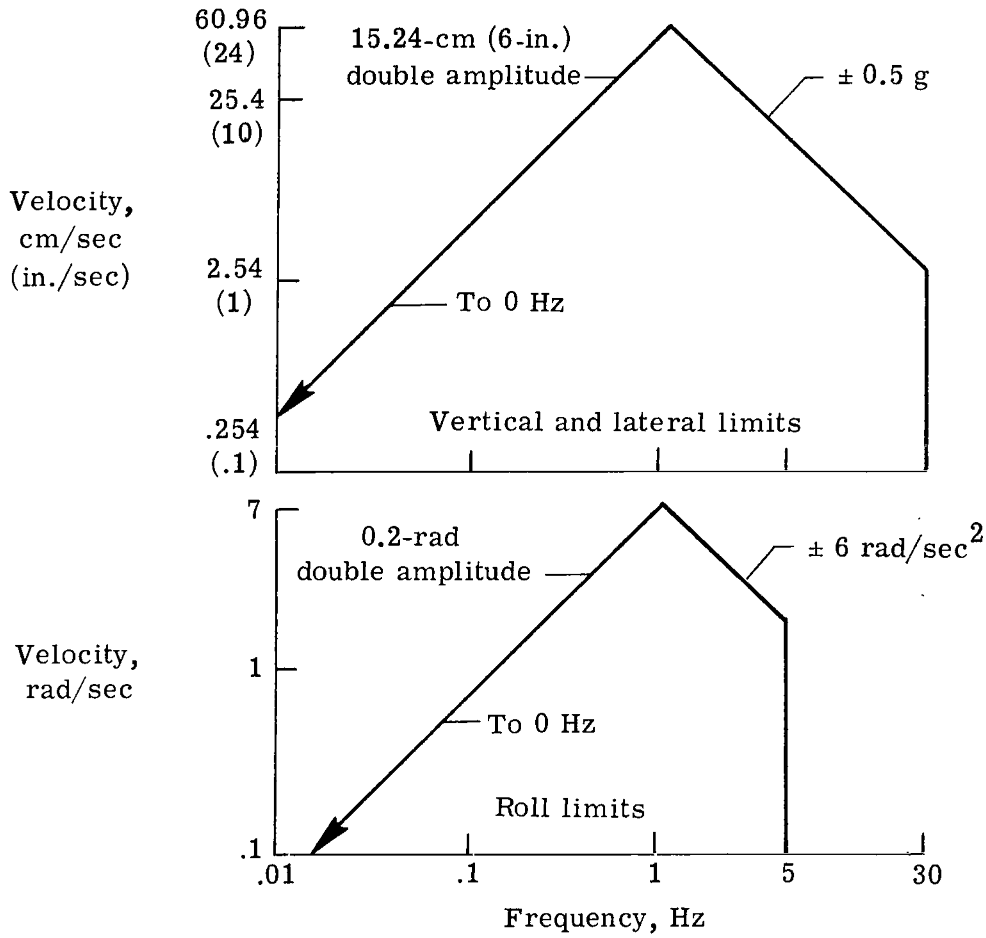
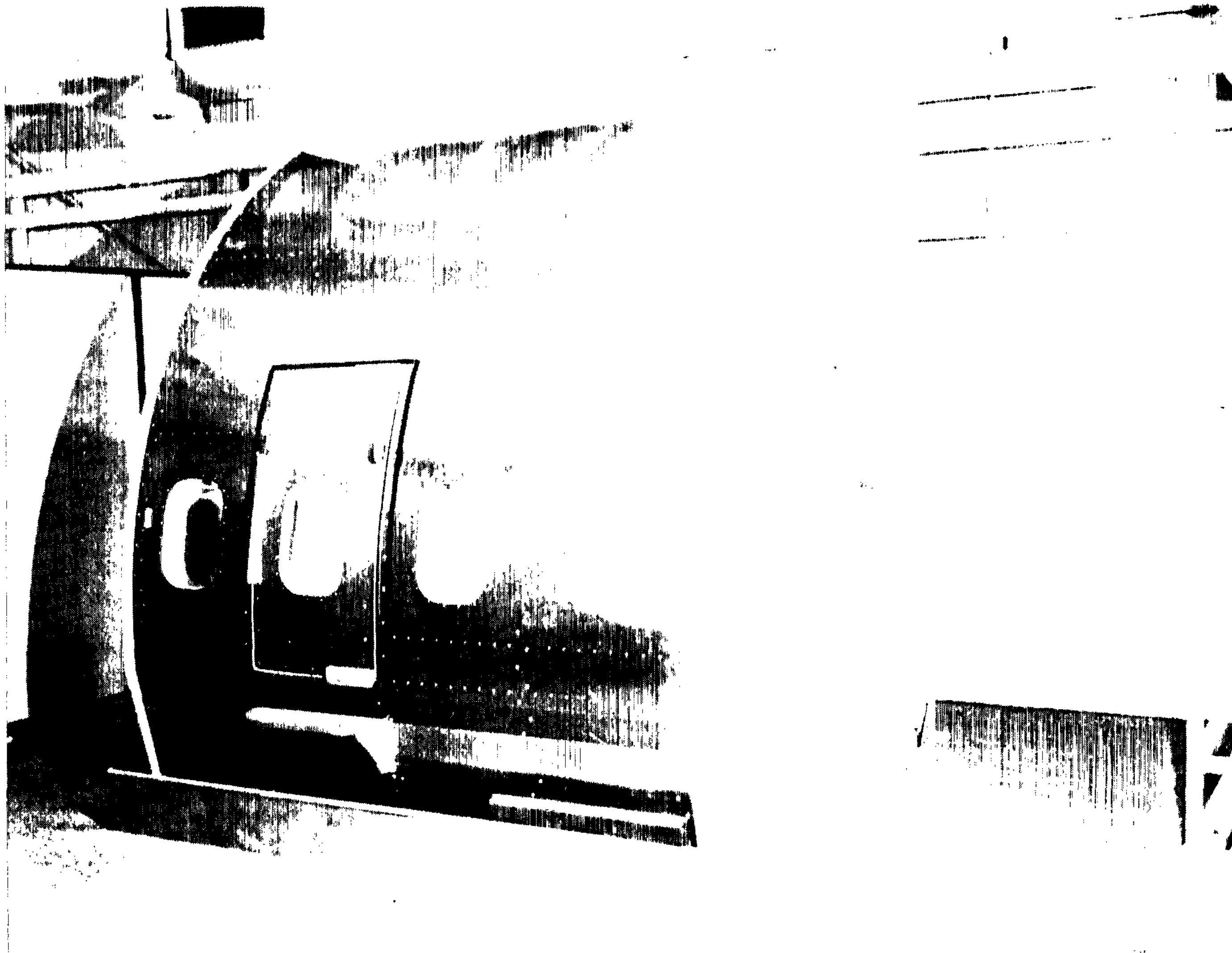


Figure 1.- Performance capabilities of the passenger ride quality apparatus. (Taken from ref. 8.)



L-73-4382

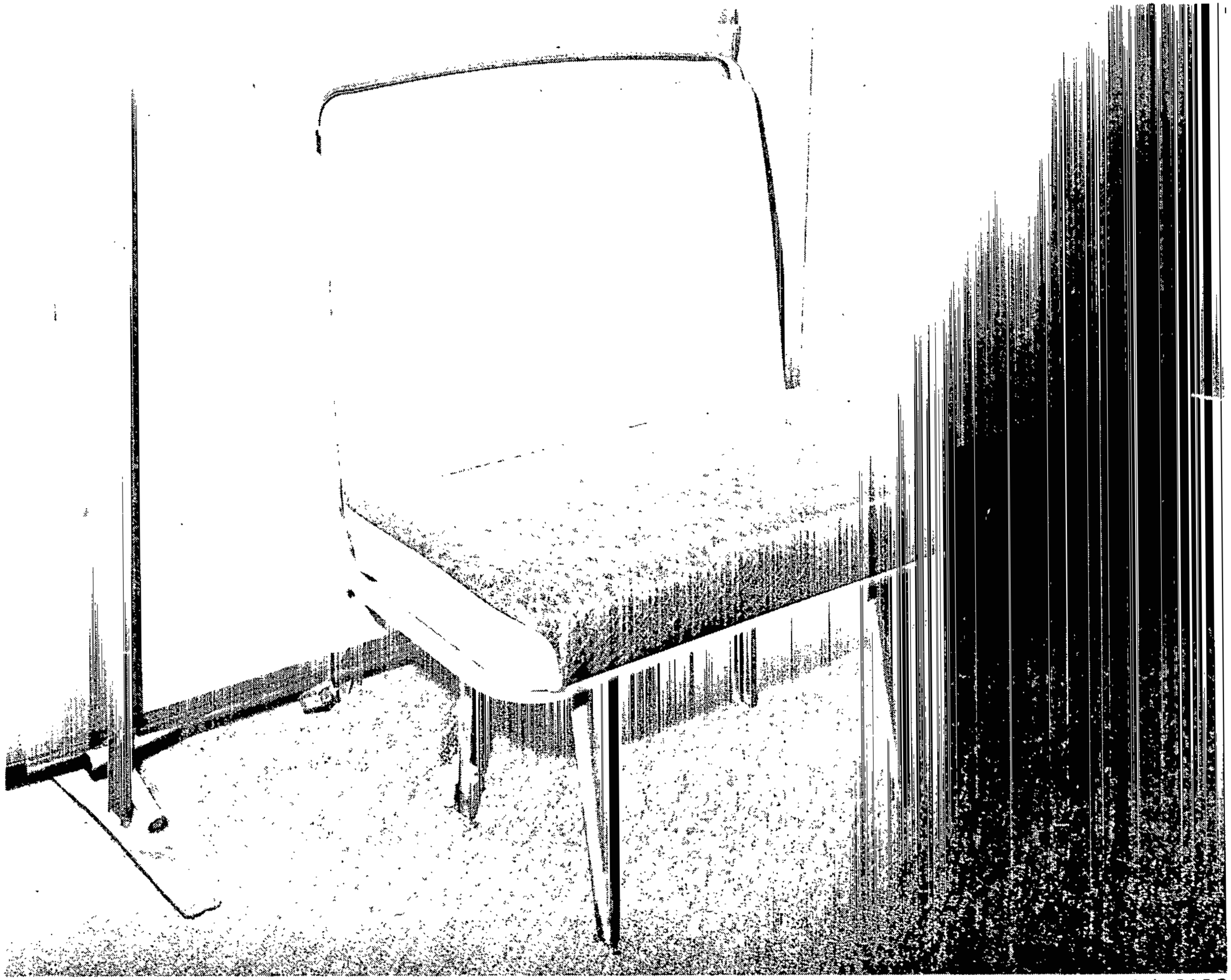
(a) Exterior view.

Figure 2.- Passenger ride quality apparatus.

L-72-5448

(b) Interior view.

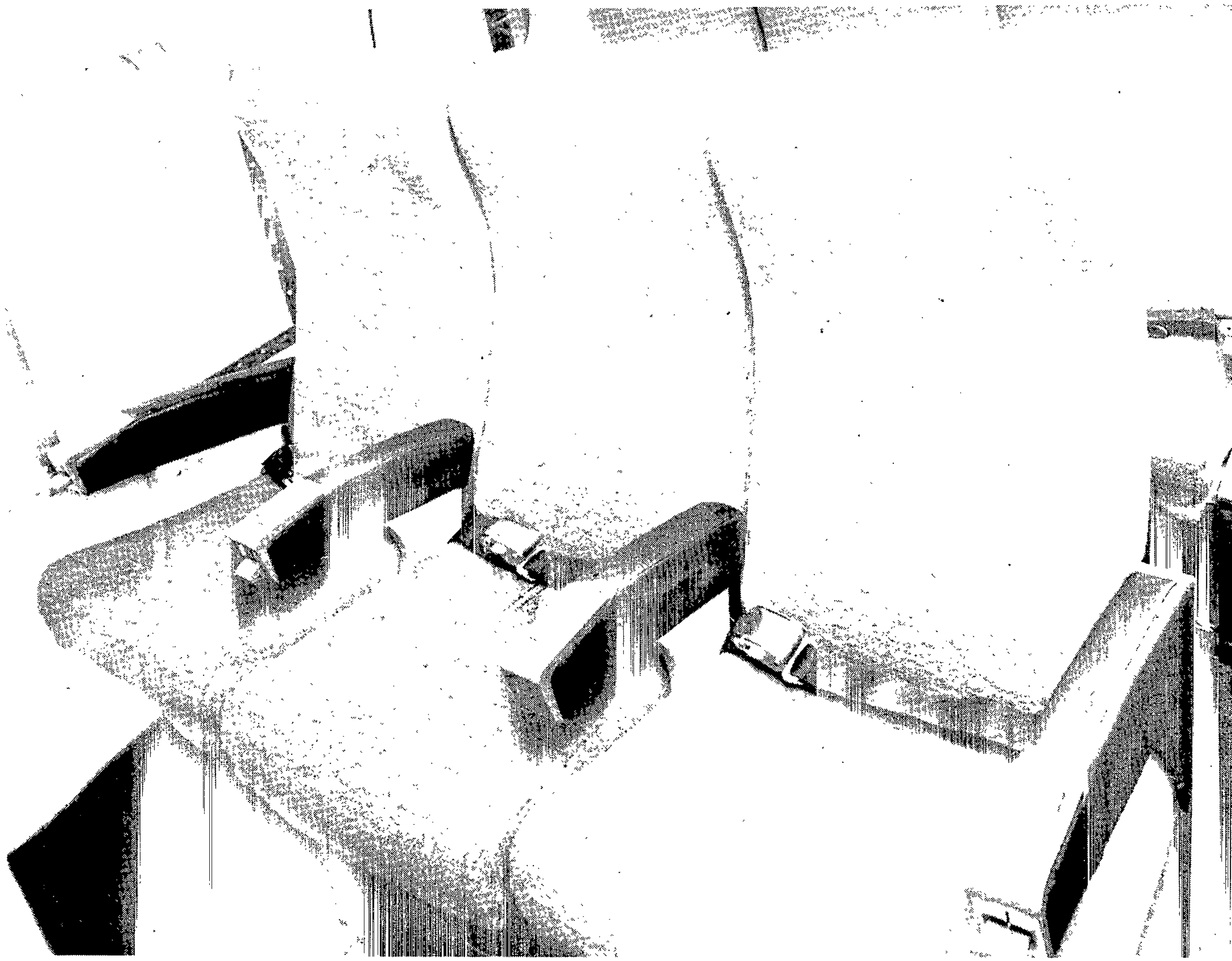
Figure 2.- Concluded.



L-74-2932

(a) Bus seats.

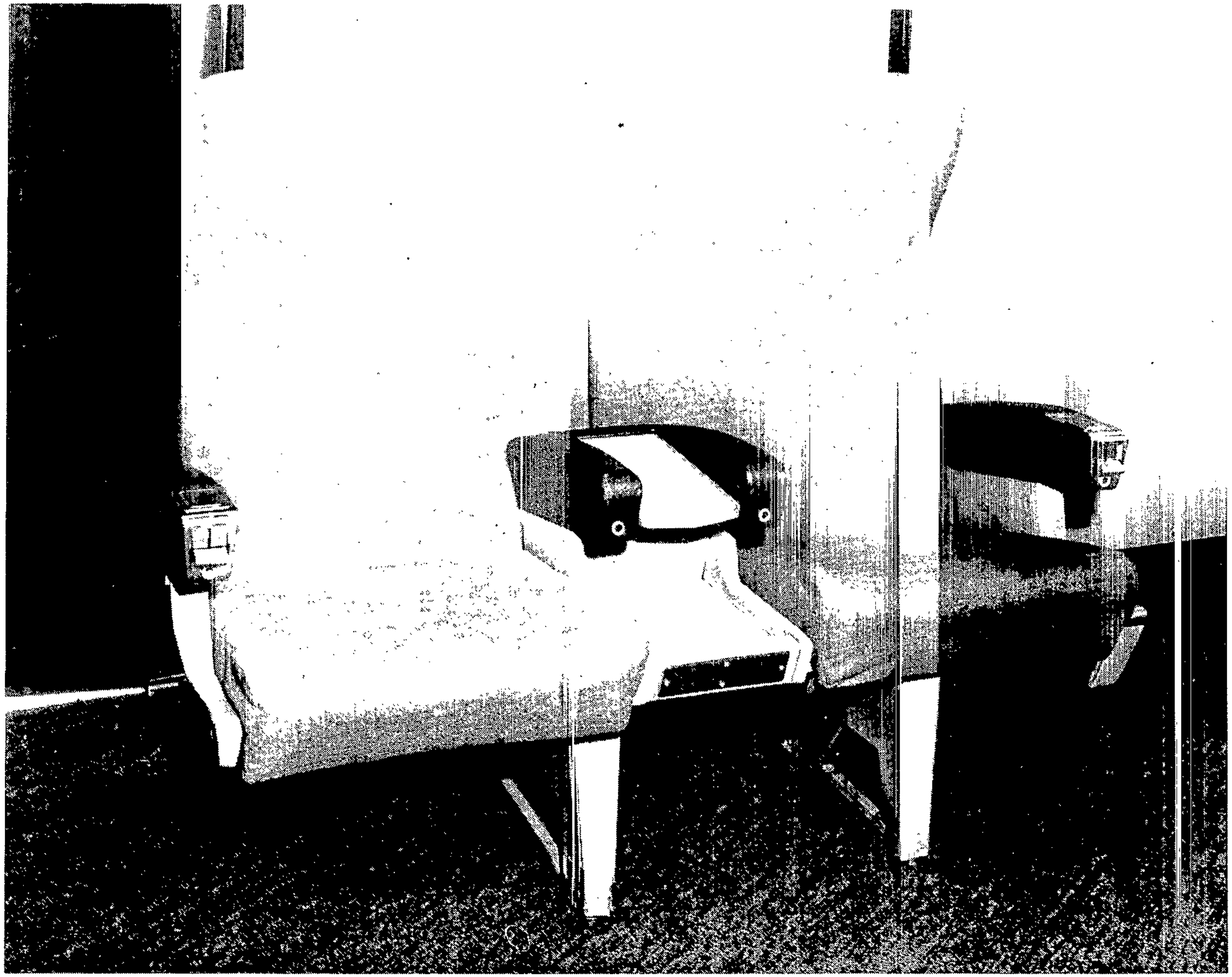
Figure 3.- Photographs of the three seat types used in this study.



L-74-2933

(b) Aircraft tourist class seats.

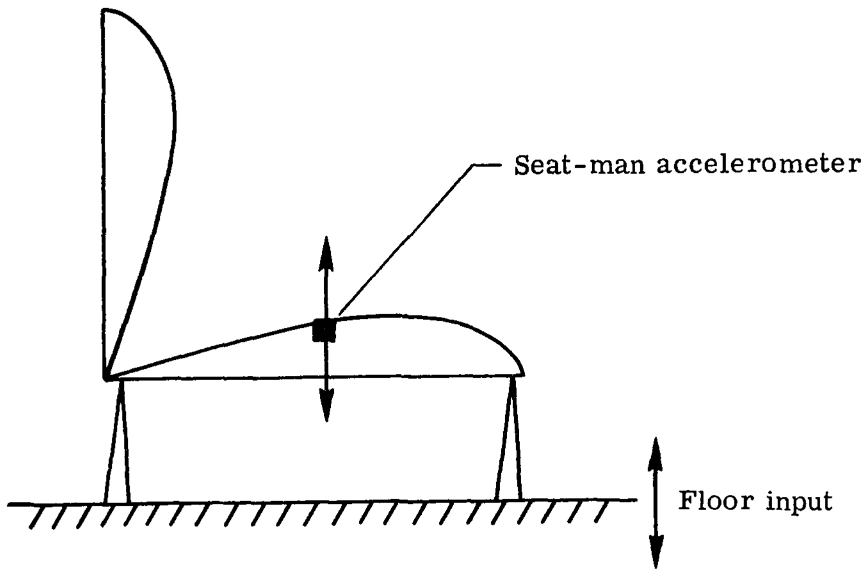
Figure 3.- Continued.



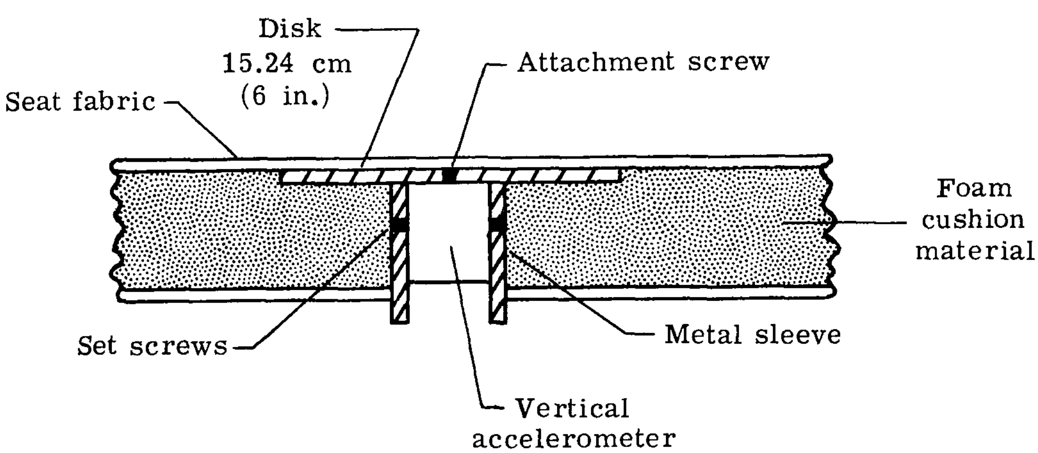
L-74-2934

(c) Aircraft first class seats.

Figure 3.- Concluded.

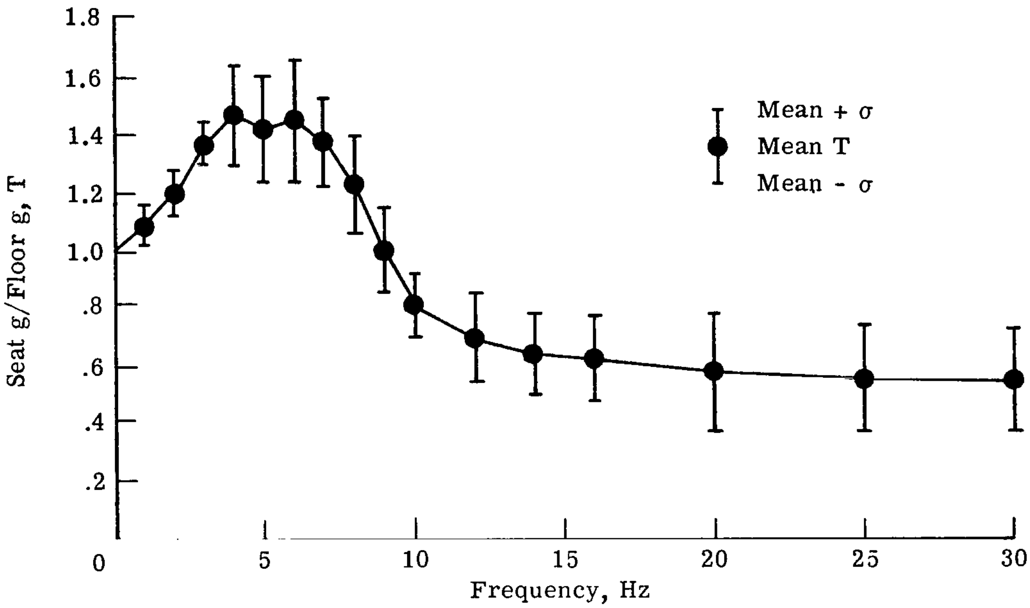


(a) Vertical accelerometer location.

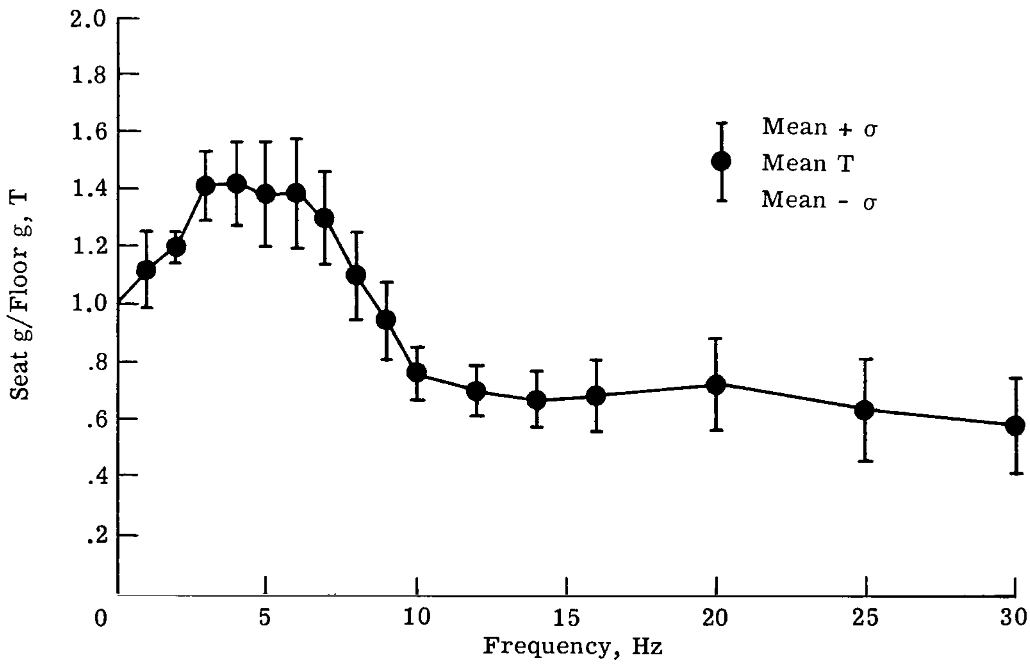


(b) Accelerometer installation detail.

Figure 4.- Details of accelerometer location and installation.
Dimensions are in centimeters (in.).

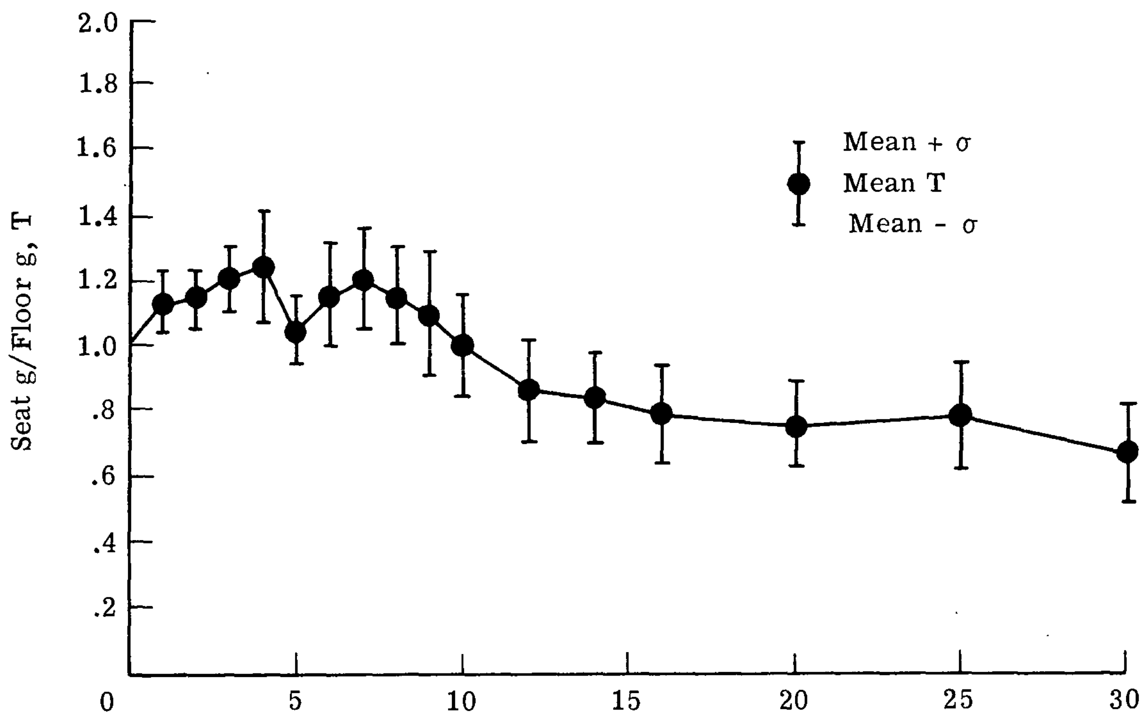


(a) Aircraft tourist class seats.



(b) Aircraft first class seats.

Figure 5.- Mean vertical transmissibility and associated variability (±1σ points) for the three seat types for a floor acceleration level of 0.10g.



(c) Bus seats.
Figure 5.- Concluded.

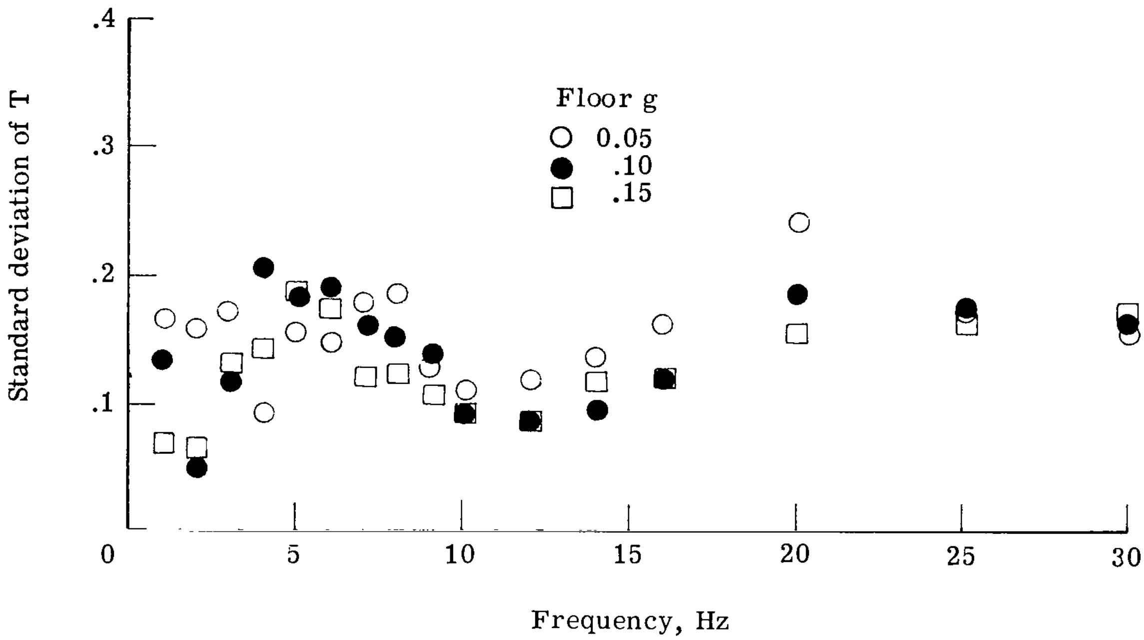


Figure 6.- Standard deviation of vertical transmissibility ratio for aircraft first class seats at three levels of floor acceleration.

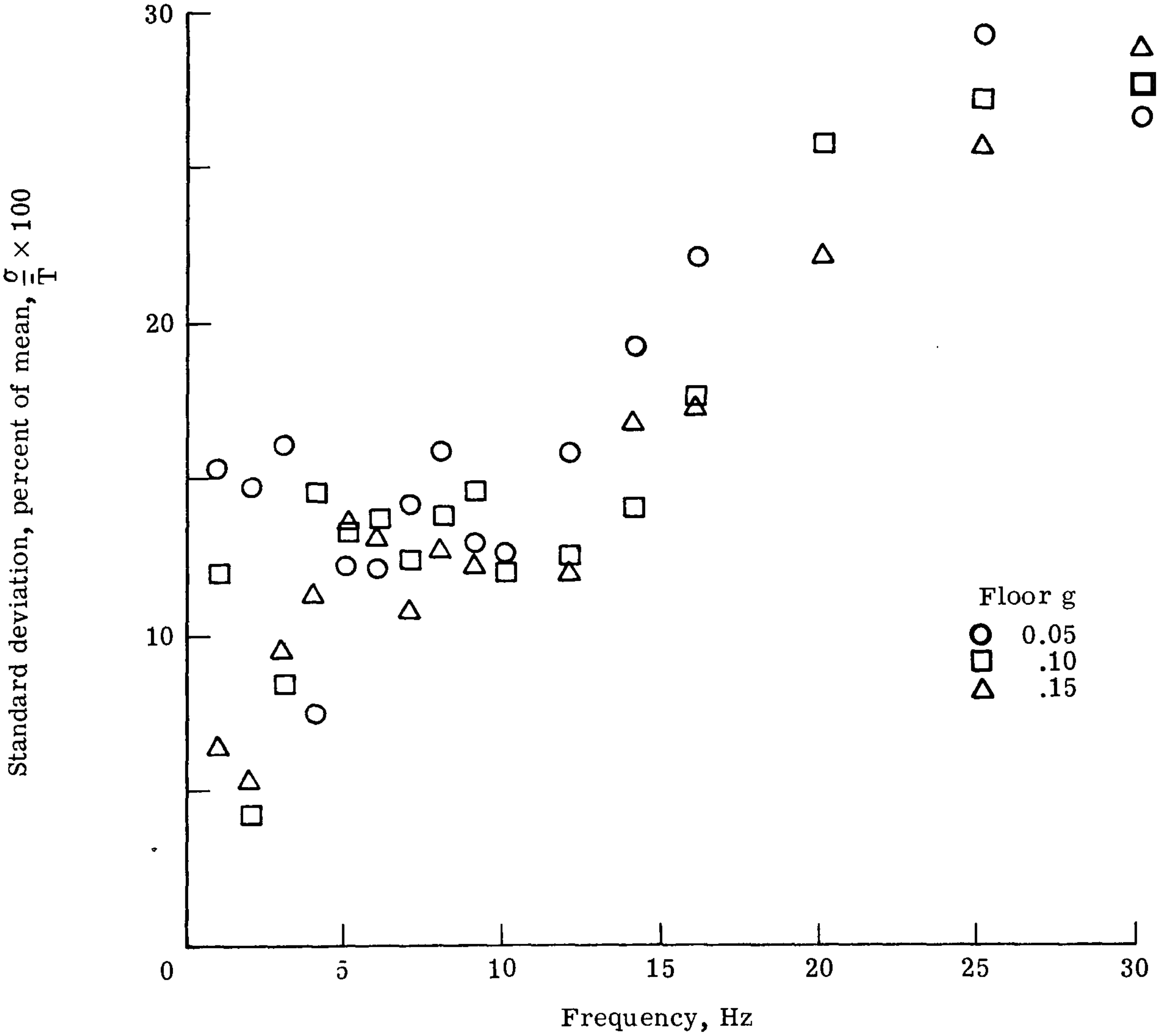


Figure 7.- Standard deviation of vertical transmissibility for aircraft first class seats in terms of the percent of mean response.

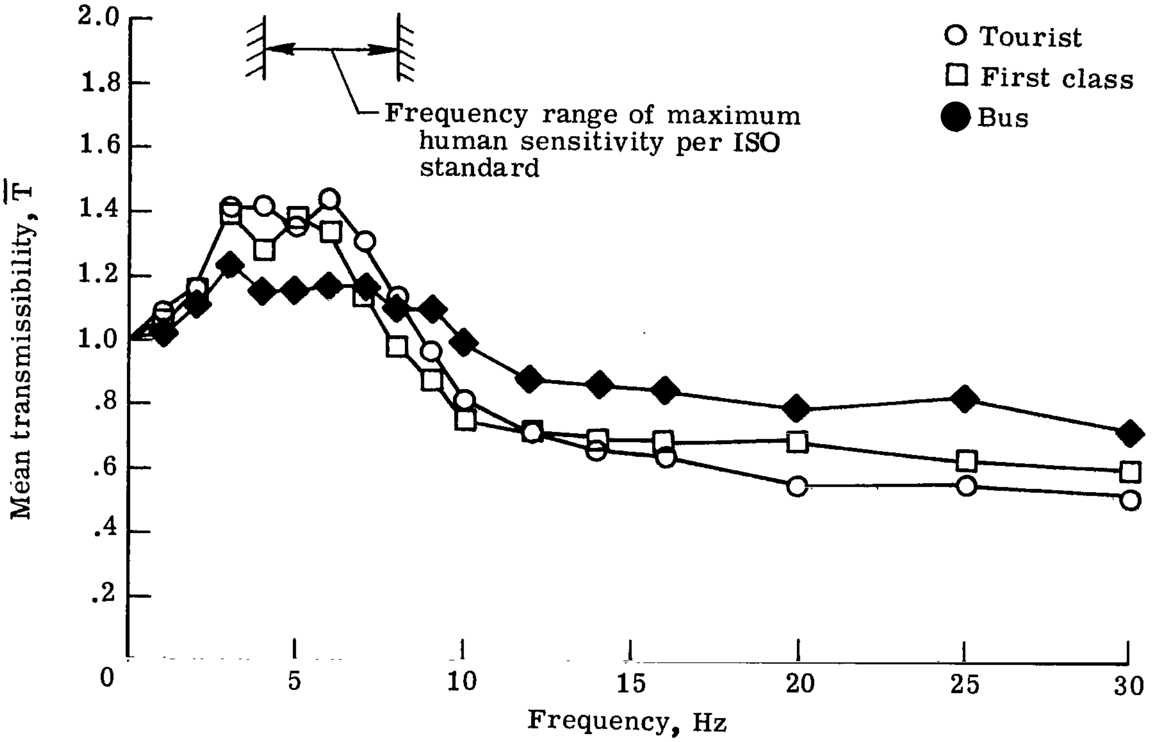


Figure 8.- Mean vertical transmissibility ratio for the three seat types at a floor acceleration level of 0.15g and comparison with ISO standards.

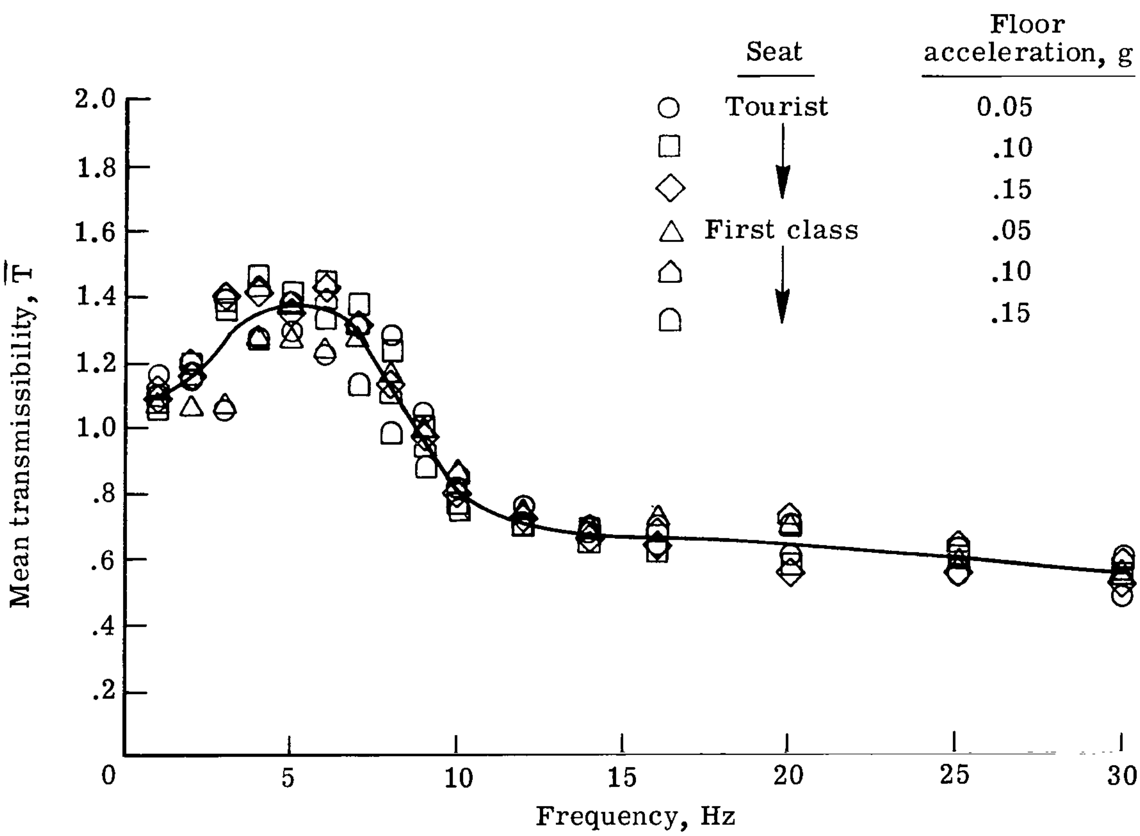
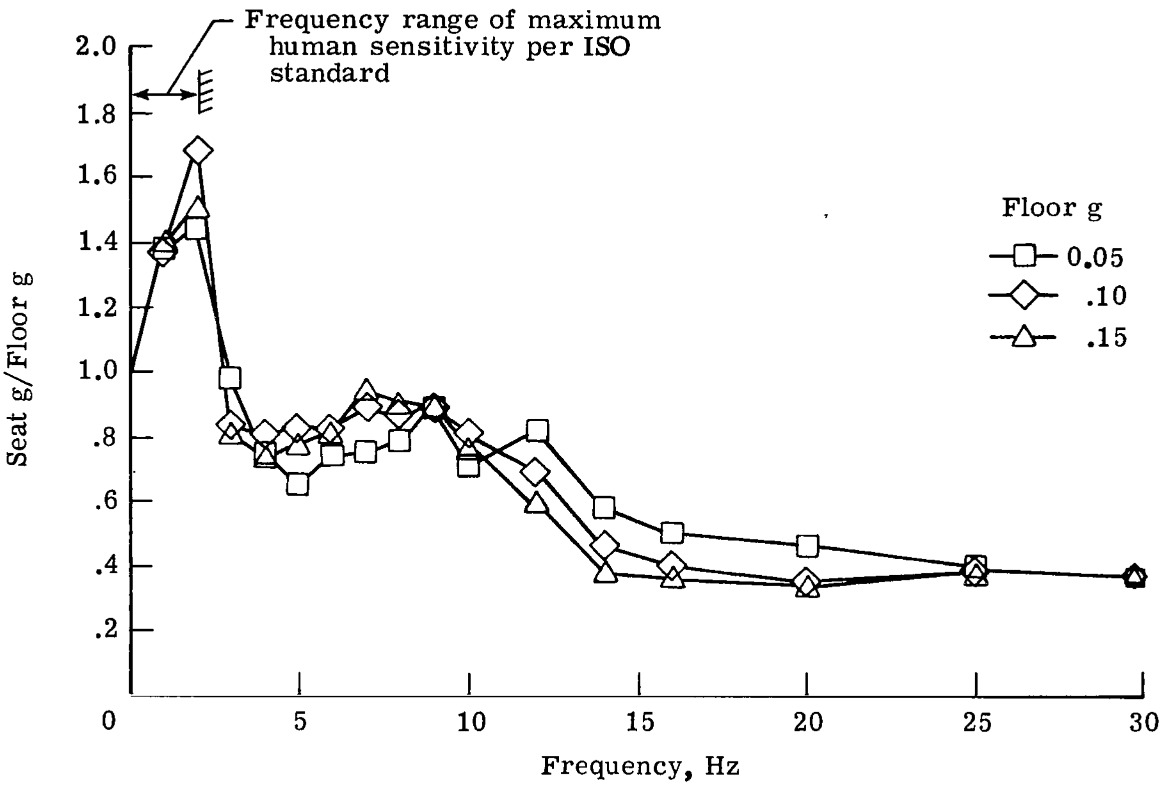
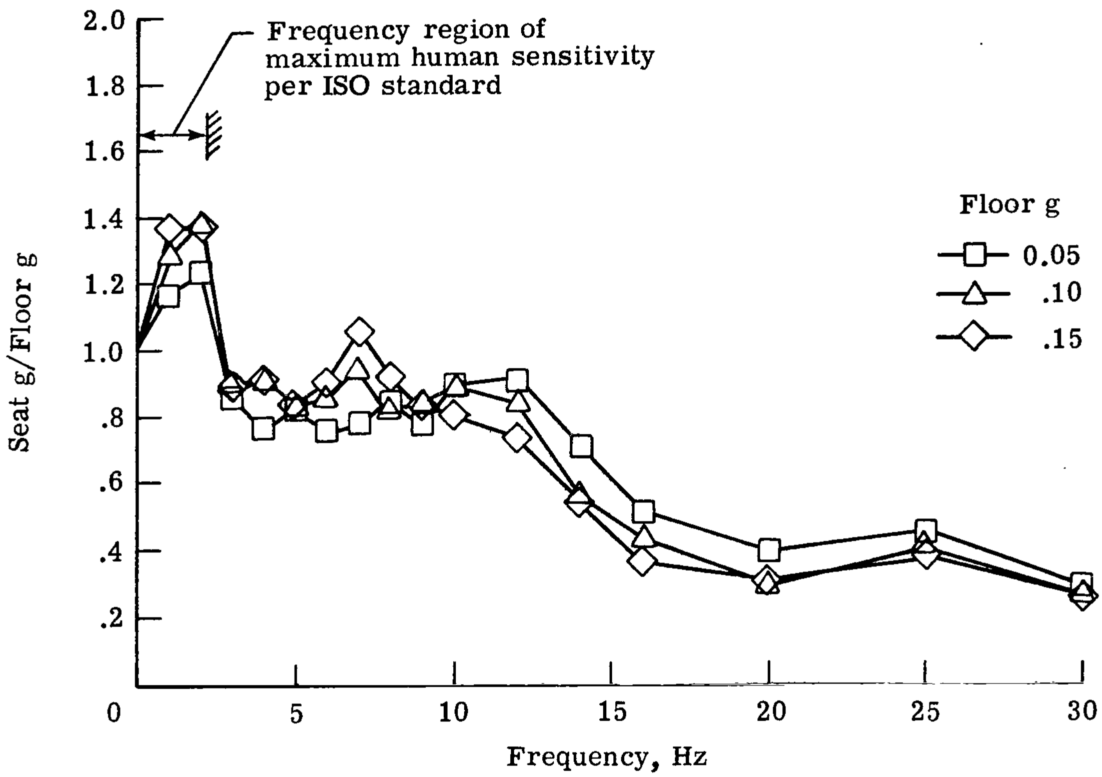


Figure 9.- Mean vertical transmissibility ratio for the aircraft seats and for all levels of floor input acceleration.



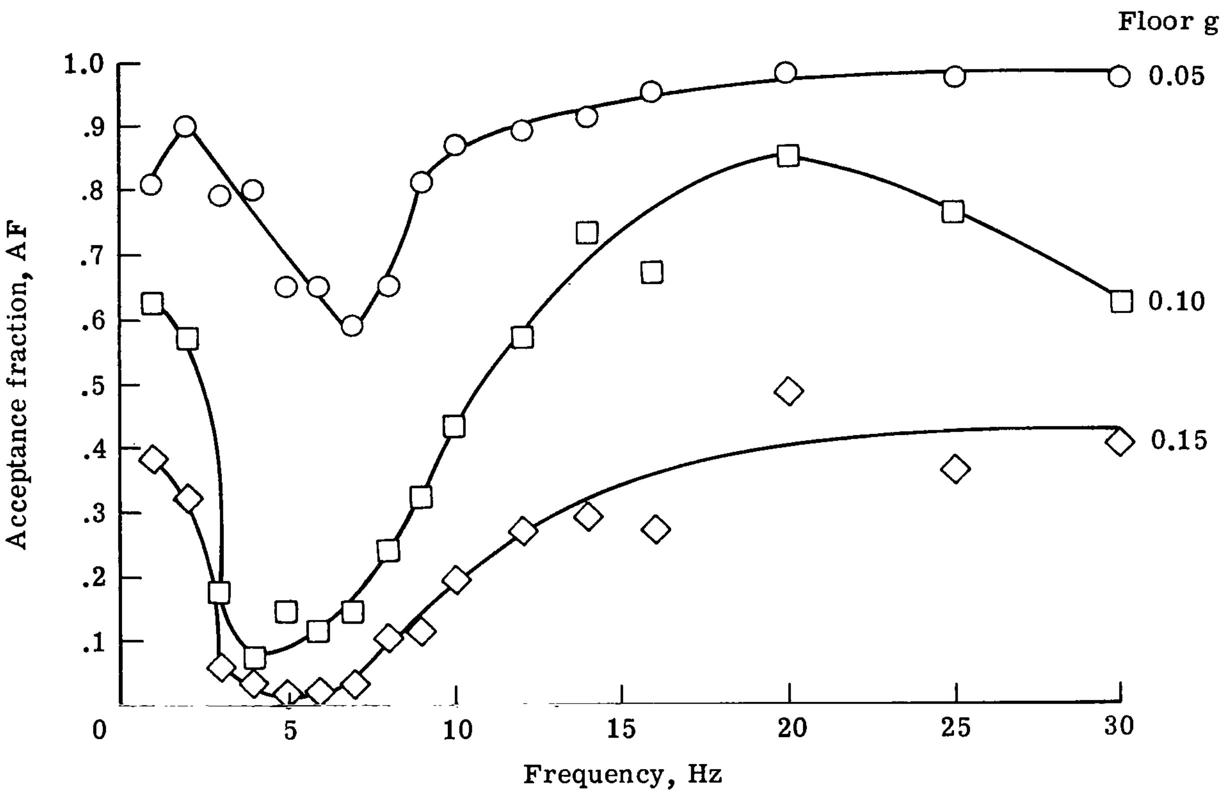
(a) First class aircraft seats.

Figure 10.- Mean transmissibility ratio in the lateral axis for aircraft seats at three nominal levels of floor acceleration and comparison with ISO standards.



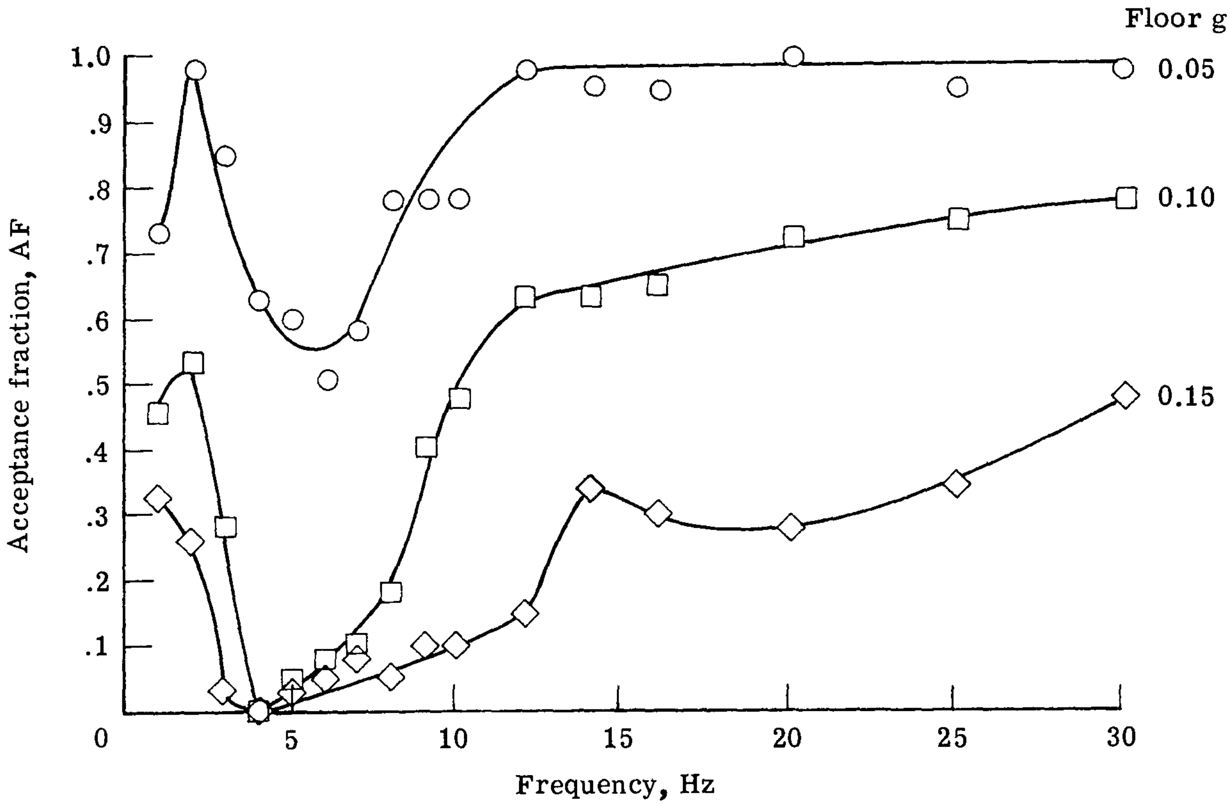
(b) Tourist class aircraft seats.

Figure 10.- Concluded.



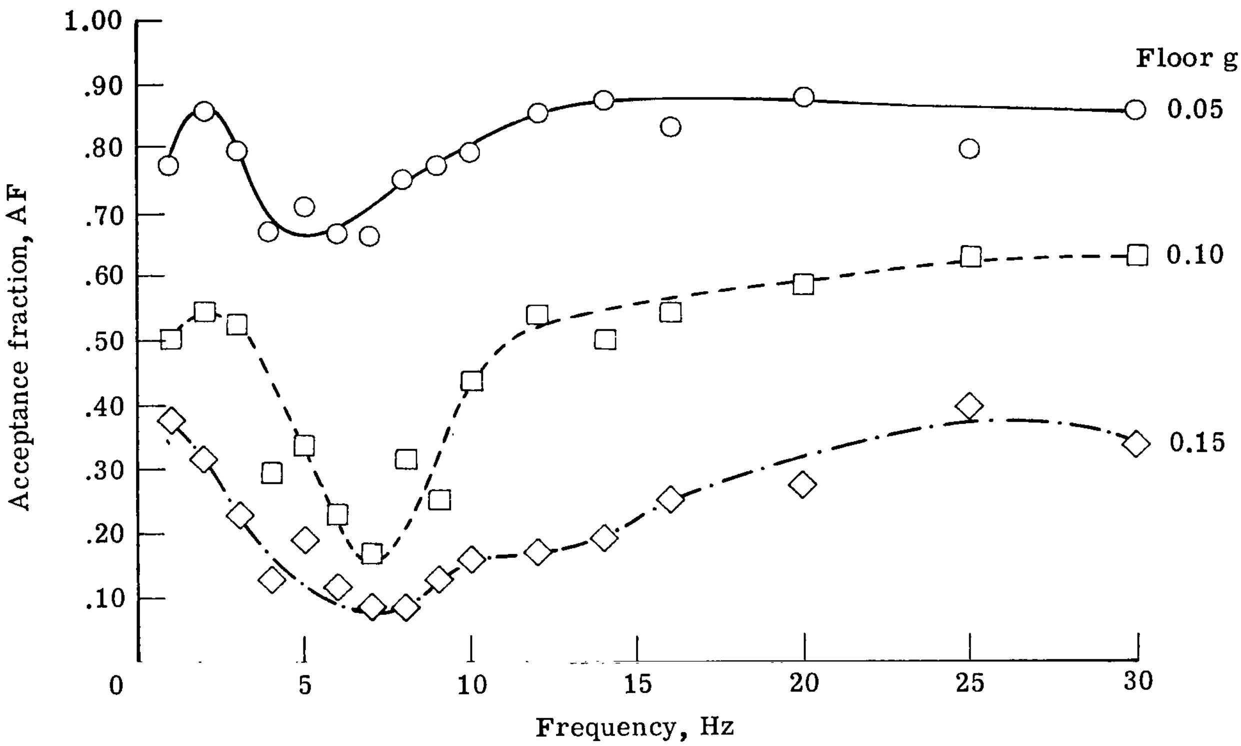
(a) Tourist class aircraft seats.

Figure 11.- Passenger acceptance of vertical vibration.



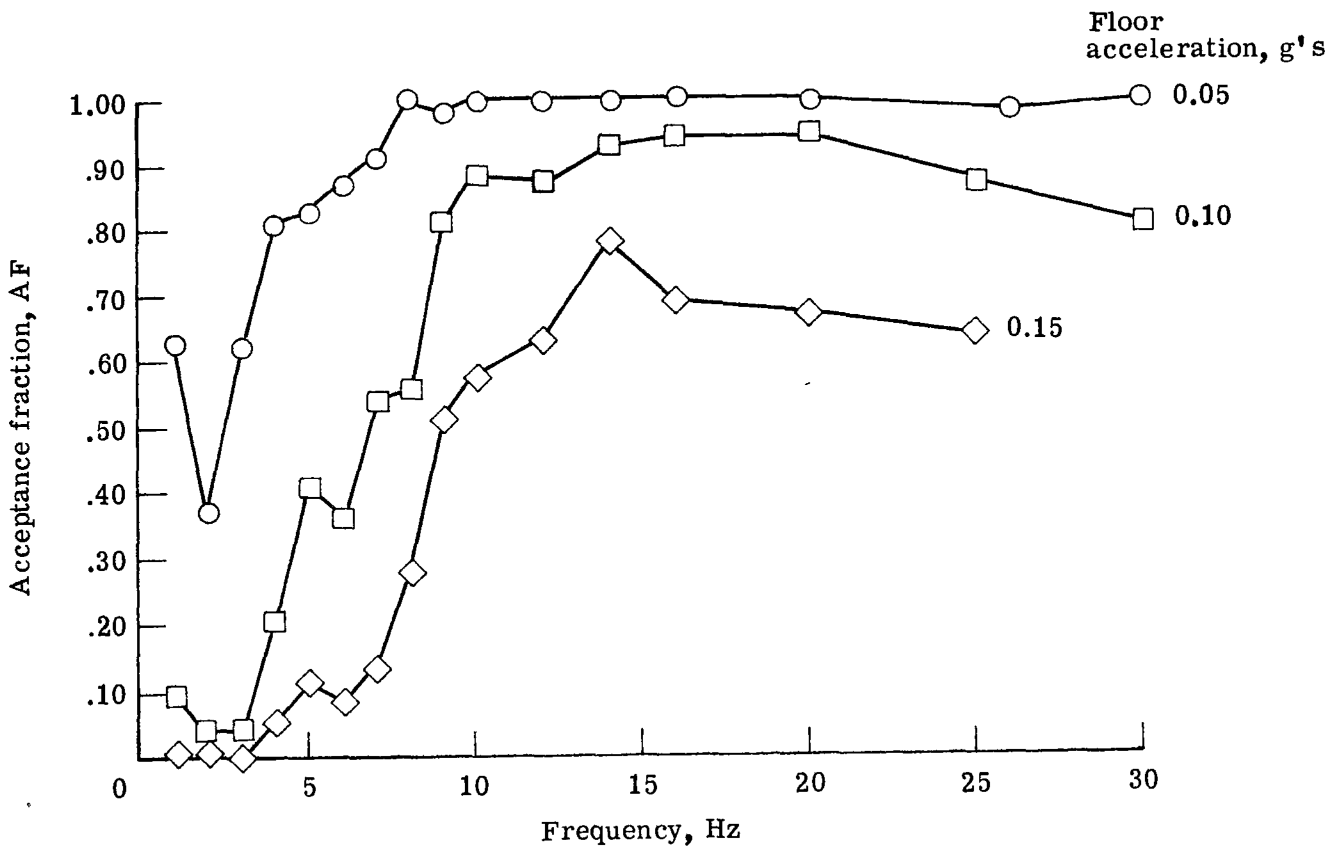
(b) First class aircraft seats.

Figure 11.- Continued.



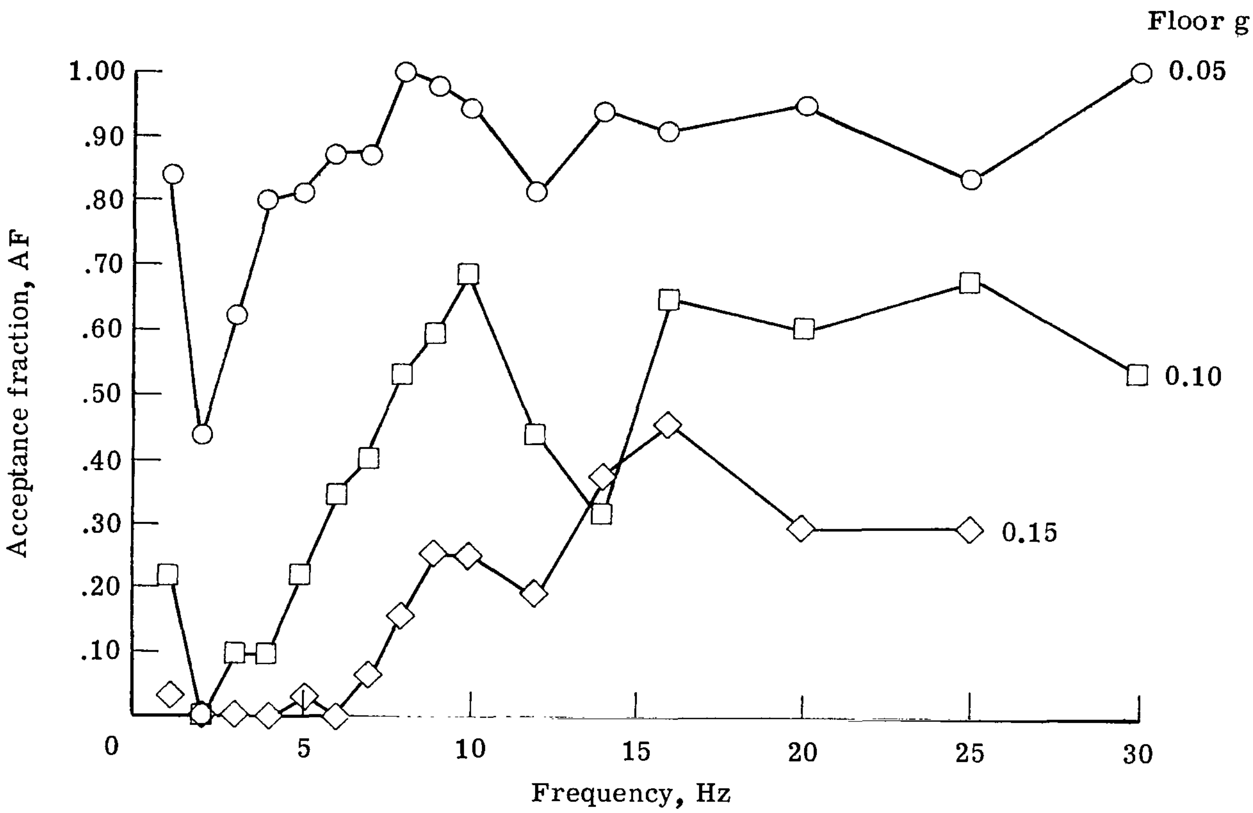
(c) Bus seats.

Figure 11.- Concluded.



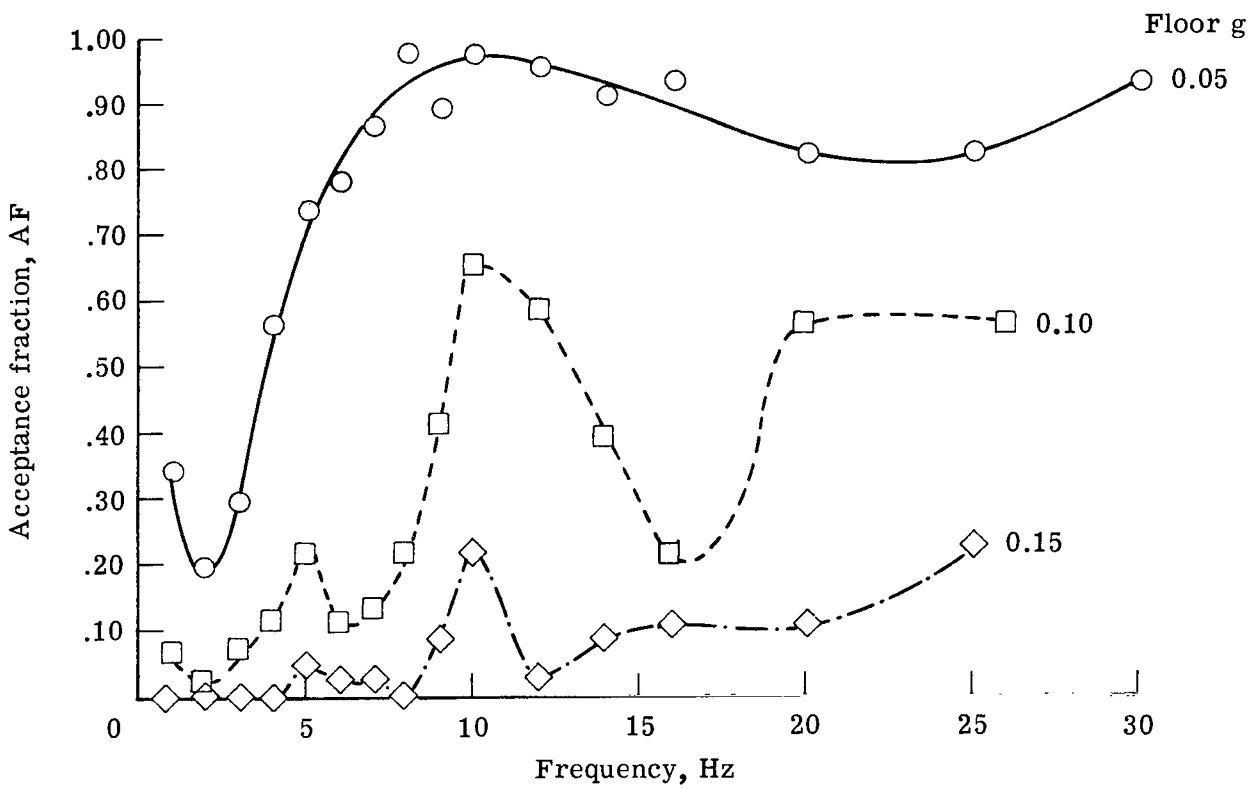
(a) Tourist class aircraft seats.

Figure 12.- Passenger acceptance of lateral vibration.



(b) First class aircraft seats.

Figure 12.- Continued.



(c) Bus seats.

Figure 12.- Concluded.

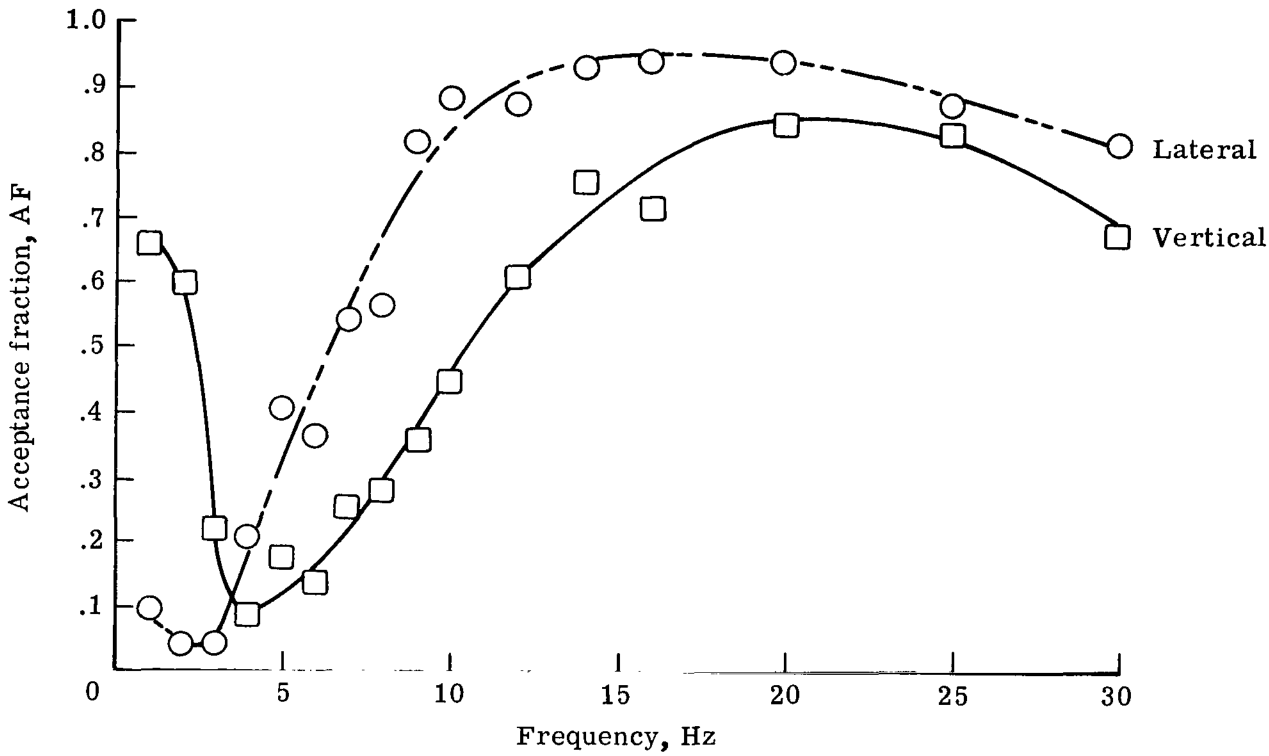


Figure 13.- Comparison of vertical and lateral acceptabilities of aircraft tourist class seats for a floor acceleration level of 0.10g.

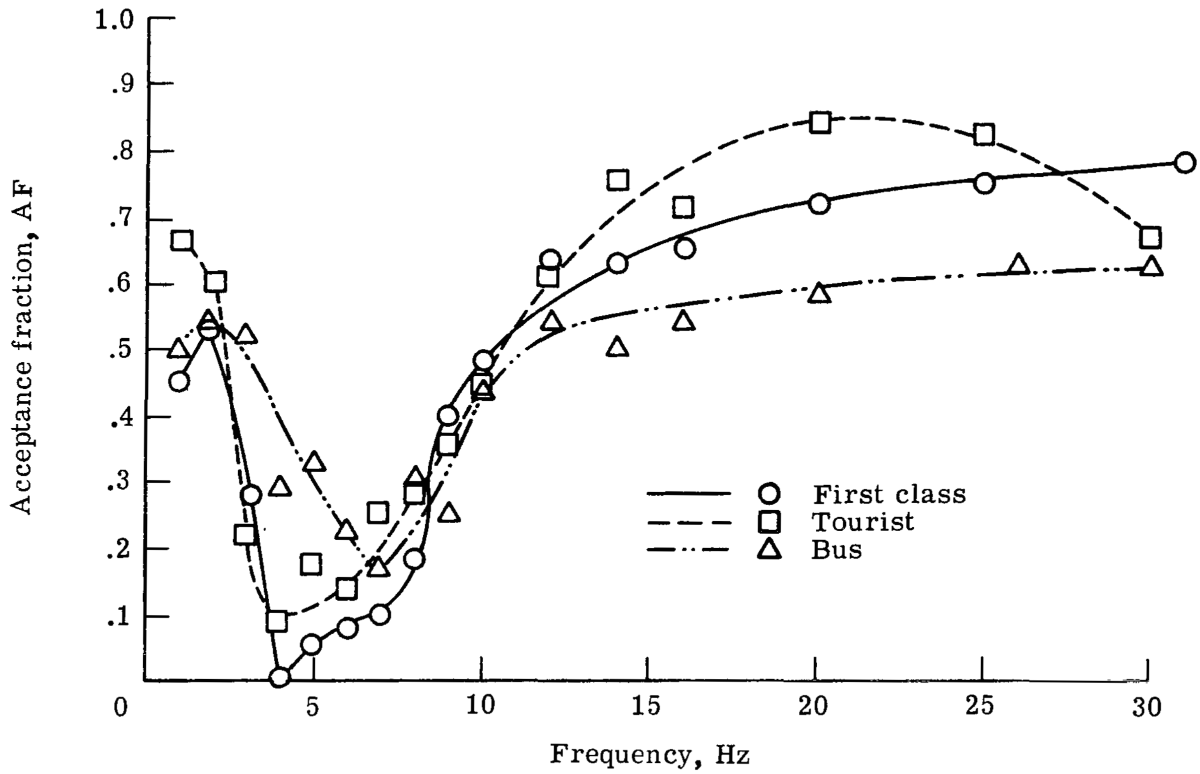


Figure 14.- Comparison of passenger acceptance of vertical vibration for the three seat types at a floor acceleration level of 0.10g.

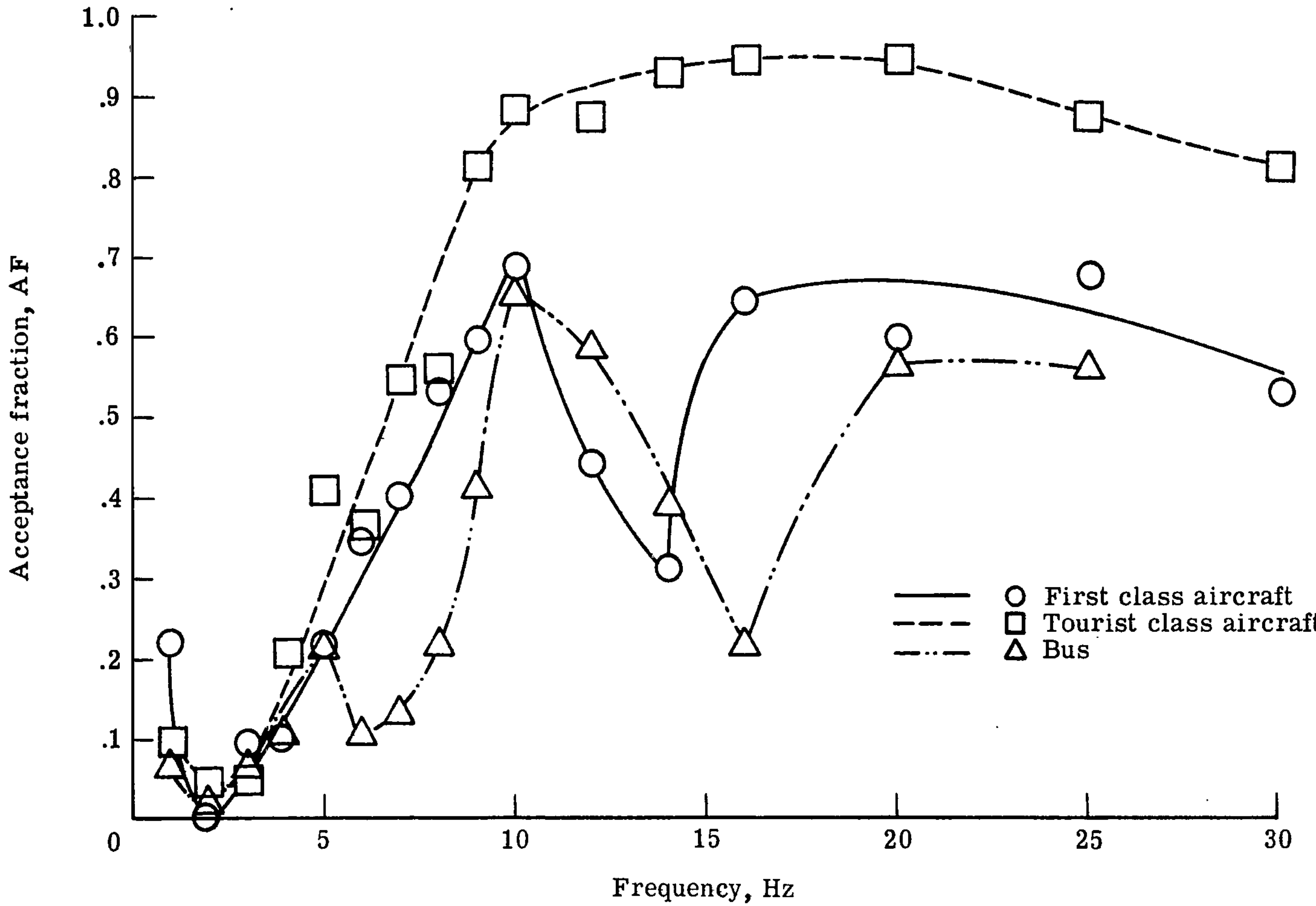
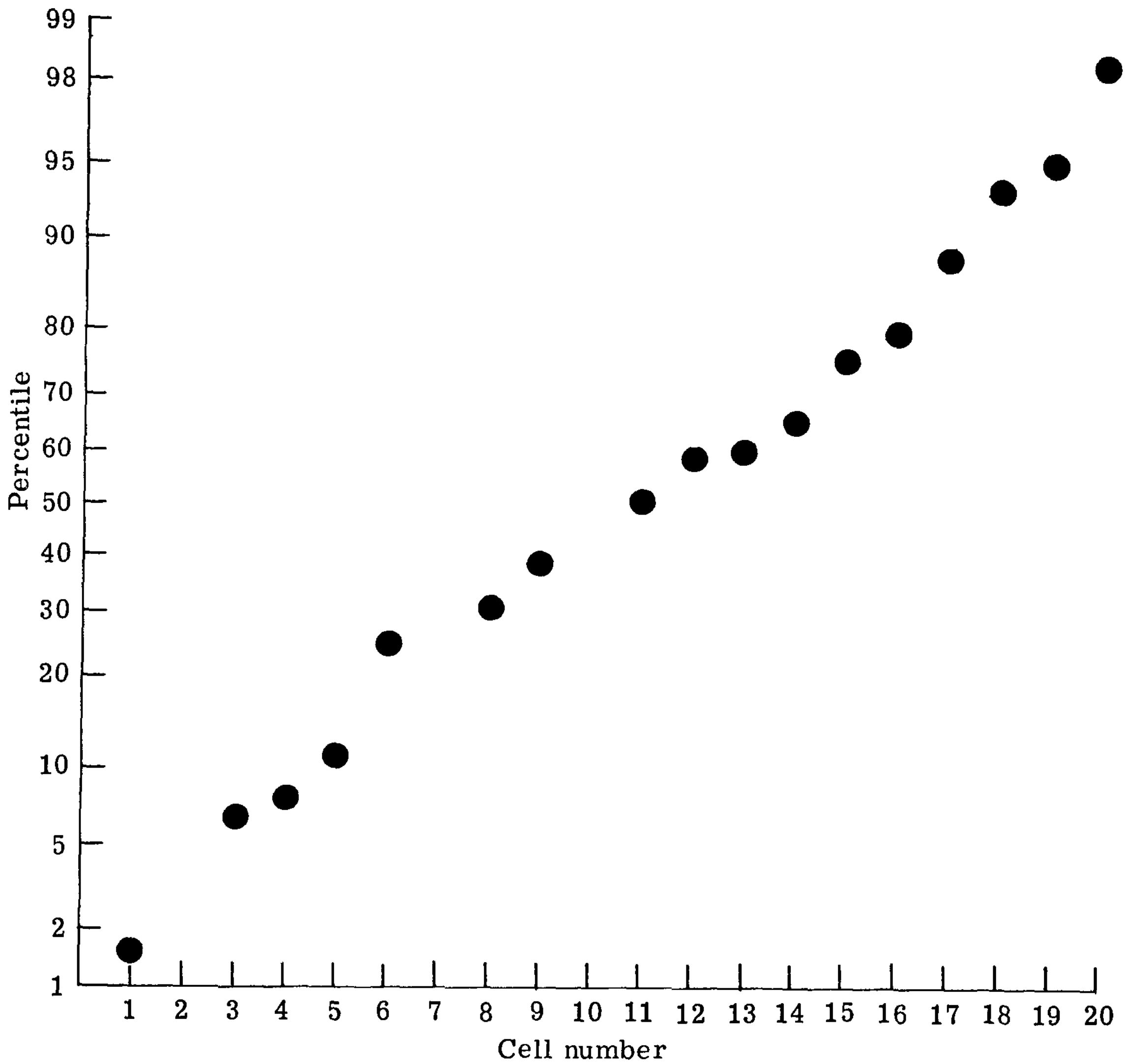
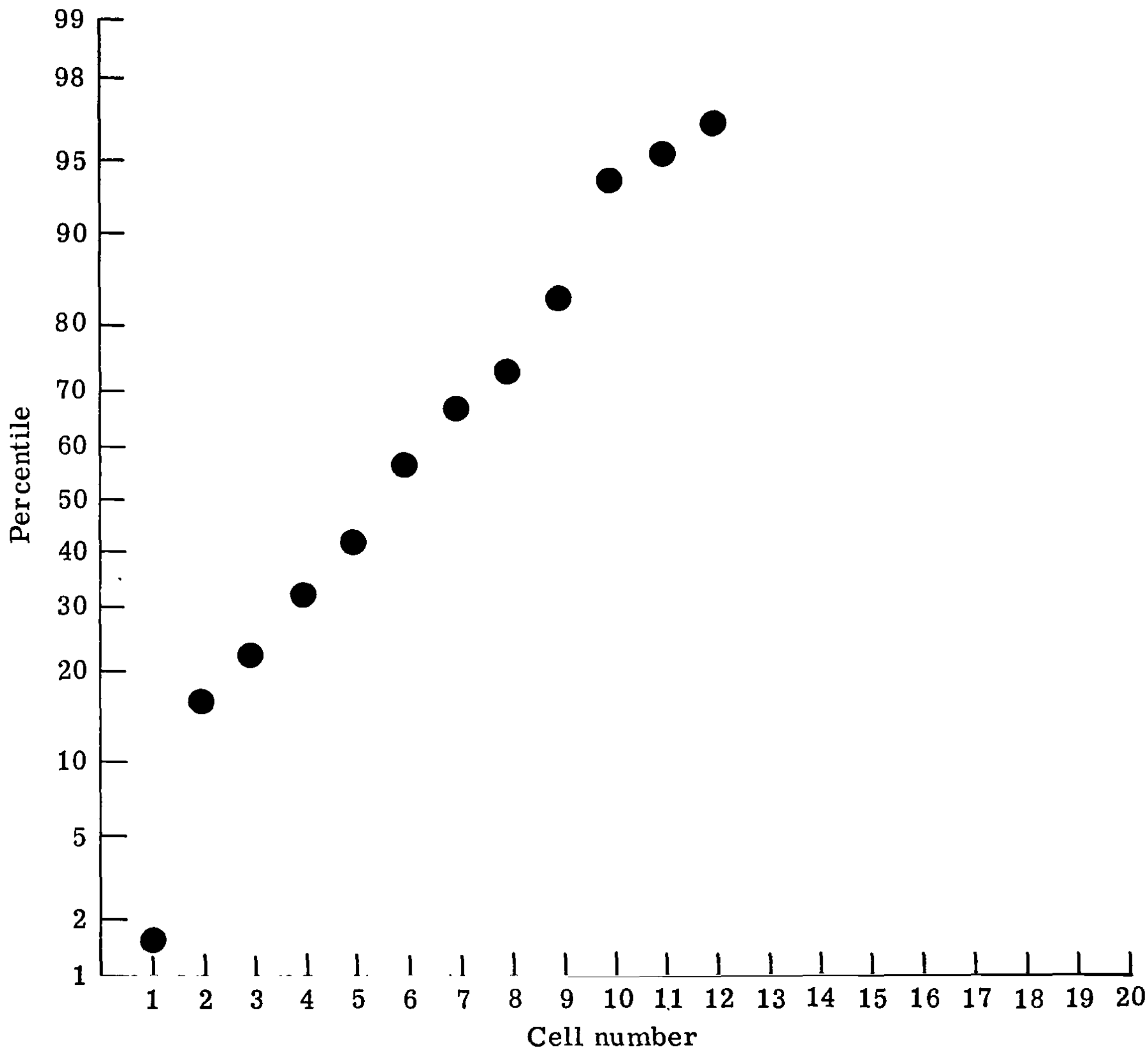


Figure 15.- Comparison of passenger acceptance of lateral vibration for the three seat types at a floor acceleration level of 0.10g.



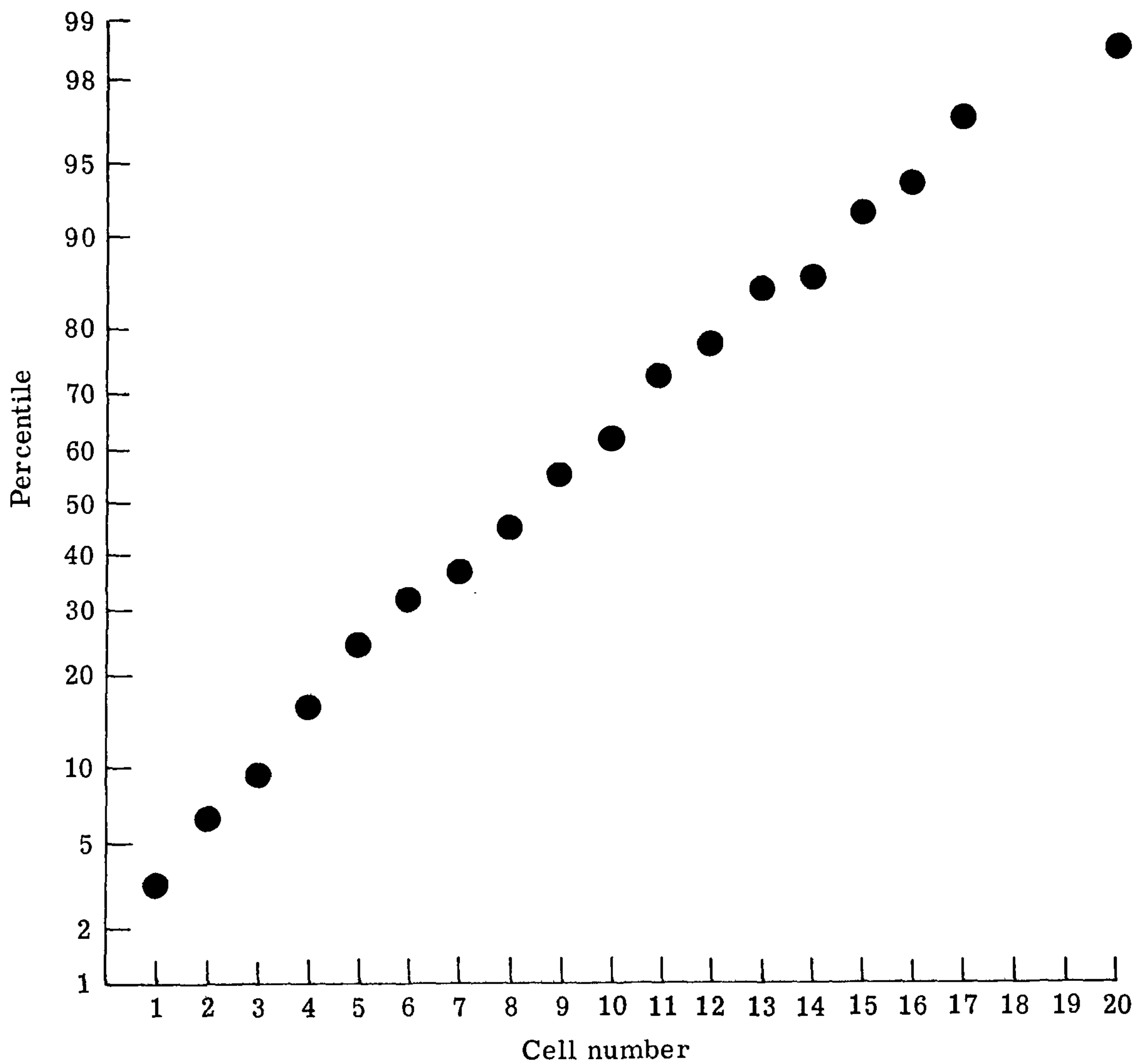
(a) Frequency, 1 Hz; cell 1, 0.9545; cell width, 0.0135.

Figure 16.- Probability distribution of transmissibility ratio for aircraft tourist class seats at a floor acceleration level of 0.10g. (All quantities are nondimensional.)



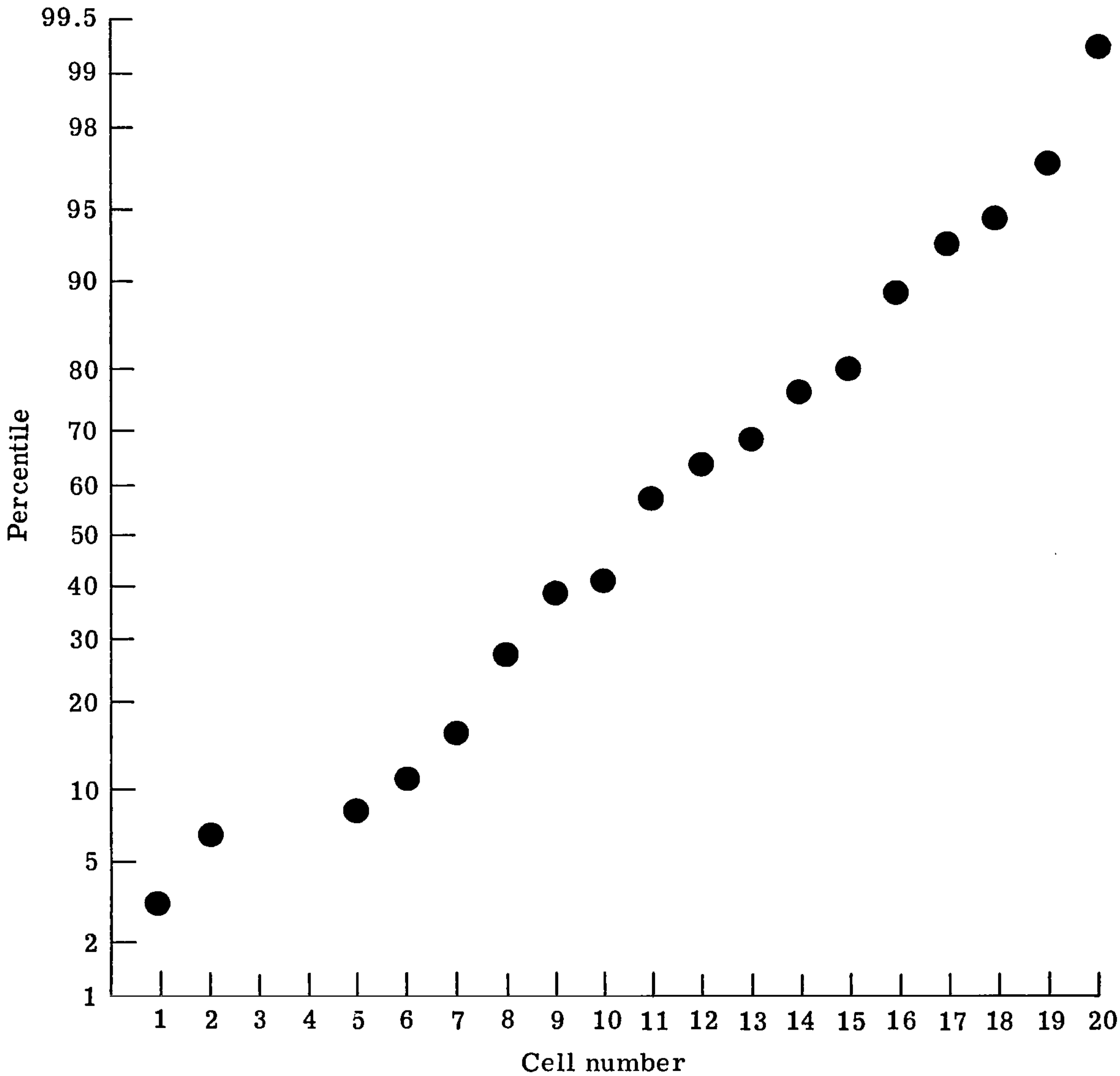
(b) Frequency, 3 Hz; cell 1, 1.2605; cell width, 0.0205.

Figure 16.- Continued.



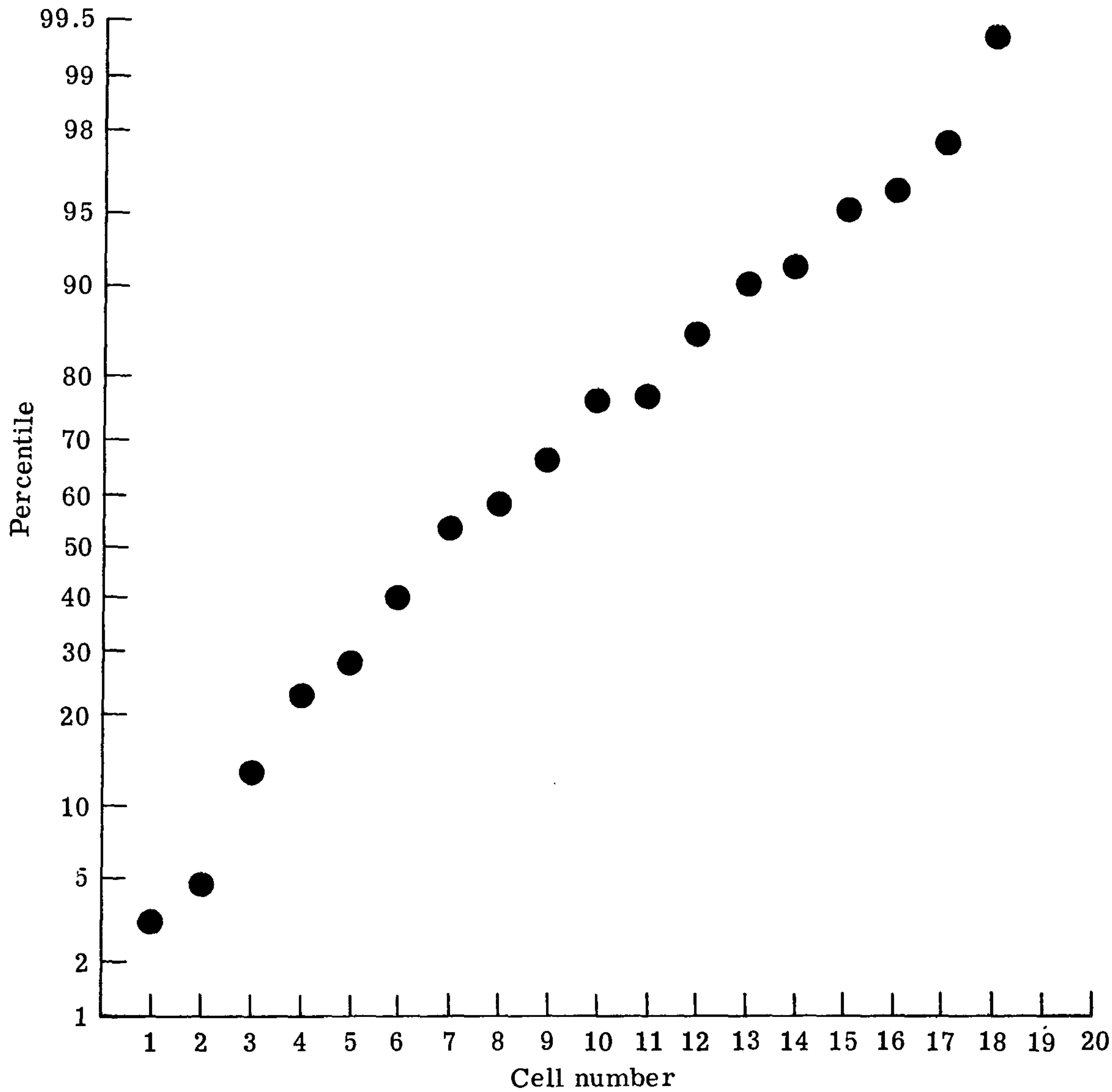
(c) Frequency, 5 Hz; cell 1, 1.1105; cell width, 0.0405.

Figure 16.- Continued.



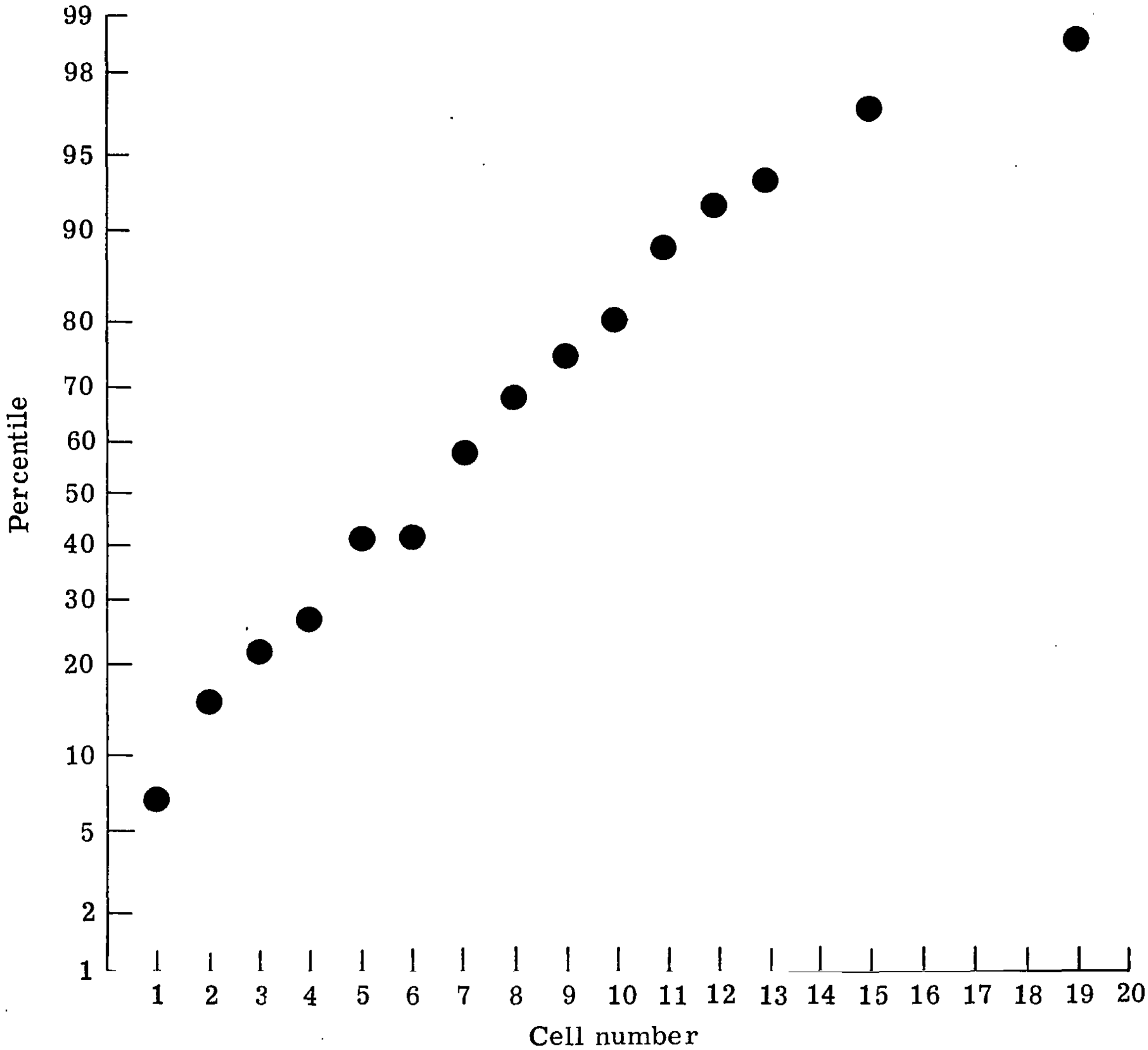
(d) Frequency, 10 Hz; cell 1, 0.593; cell width, 0.023.

Figure 16.- Continued.



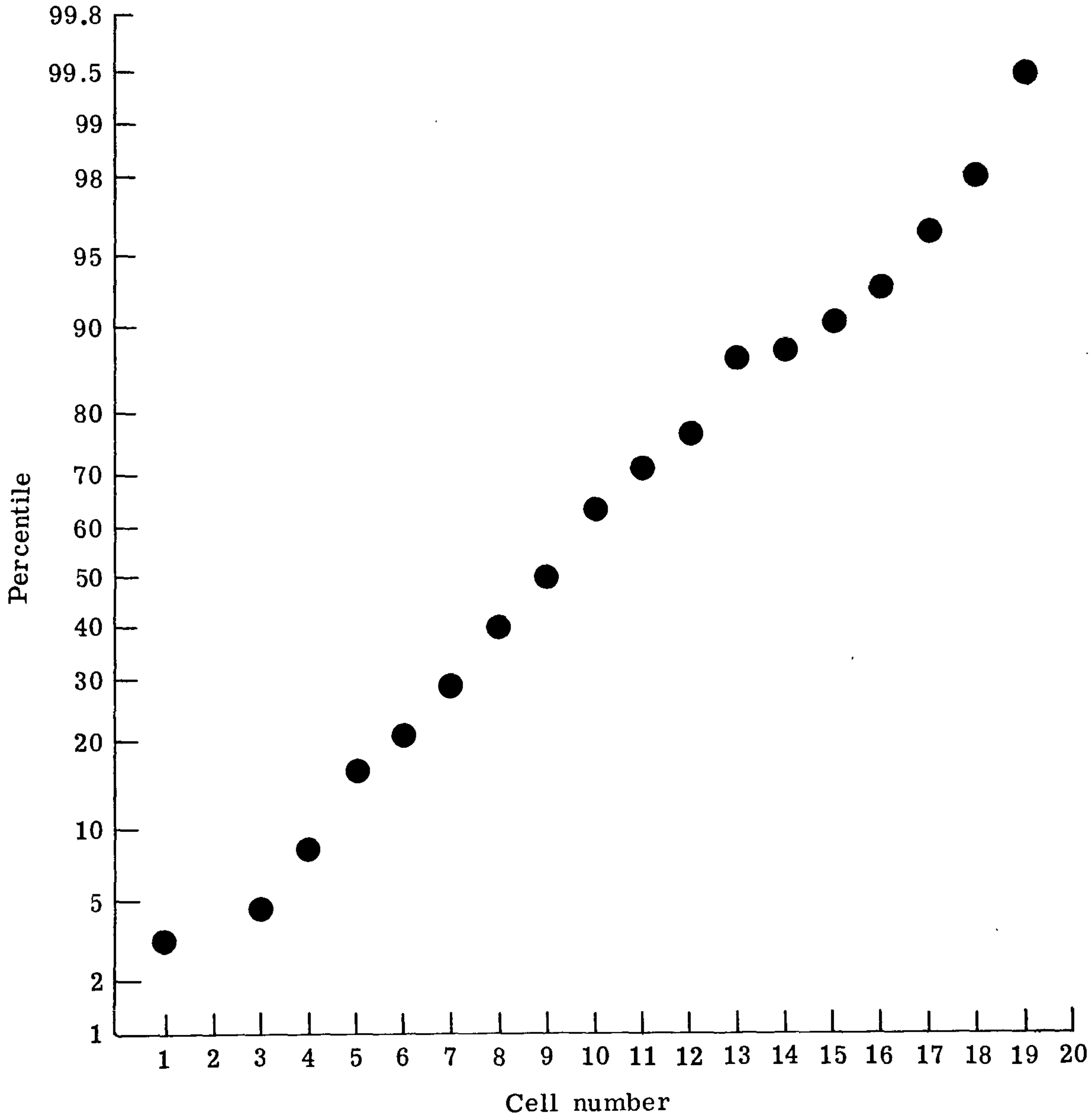
(e) Frequency, 16 Hz; cell 1, 0.3945; cell width, 0.0345.

Figure 16.- Continued.



(f) Frequency, 20 Hz; cell 1, 0.3170; cell width, 0.0470.

Figure 16.- Continued.



(g) Frequency, 30 Hz; cell 1, 0.1815; cell width, 0.0415.

Figure 16.- Concluded.

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