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A METHOD FOR THE MEASUREMENT  
AND ANALYSIS OF RIDE VIBRATIONS  
OF TRANSPORTATION SYSTEMS

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# A METHOD FOR THE MEASUREMENT AND ANALYSIS OF RIDE VIBRATIONS OF TRANSPORTATION SYSTEMS

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## SUMMARY

The measurement and recording of ride vibrations which affect passenger comfort in transportation systems and the subsequent data-reduction methods necessary for interpreting the data present exceptional instrumentation requirements and necessitate the use of computers for specialized analysis techniques. This paper presents a method for both measuring and analyzing ride vibrations of the type encountered in ground and air transportation systems. A portable system for measuring and recording low-frequency, low-amplitude accelerations and specialized data-reduction procedures are described. Sample vibration measurements in the form of statistical parameters representative of typical transportation systems are also presented to demonstrate the utility of the techniques.

## INTRODUCTION

One important consideration in the design of any public transportation system is passenger comfort, or the ride quality required to assure passenger acceptance. Extended periods of low-altitude flight with STOL aircraft or lengthy trips on high-speed trains over unimproved track have revealed that ride-quality considerations are of major importance for such systems. However, very little quantitative or descriptive information exists on ride quality since ride is affected by a number of circumstances which include not only environmental comfort but also the ability of the passengers to do simple tasks such as reading and writing. Part of the difficulty in developing ride criteria stems from the problem of measuring, recording, and analyzing the dynamic environment associated with public transportation vehicles.

Many investigators have studied the problem by subjecting people seated on platforms to sinusoidal motions. (For some examples, see refs. 1, 2, and 3.) However, in reality, vehicle motion is multidimensional and random in nature.

As part of an ongoing program to examine the effect of vibration on human comfort, an investigation has been conducted whereby field measurements of ride vibrations on a number of different vehicles have been obtained, and a data inventory has been established

compiling acceleration measurements along the three principal axes of these vehicles within the passenger spaces. Some results from these tests have been reported in references 4 to 8 and include such vehicles as short take-off and landing (STOL) aircraft, conventional take-off and landing (CTOL) jet transport aircraft, helicopters, trains, and automobiles. Measurements obtained from such tests are correlated with engineering-type judgments of ride quality (ad hoc subjective reactions by test engineers) whenever possible, and the vibrational characteristics of the vehicles such as frequency and acceleration magnitudes that particularly influence ride comfort as reported by the test engineers are tentatively identified.

The purpose of this report is to present the method or technique employed for measuring, analyzing, and interpreting vibratory accelerations associated with passenger vehicles. The report describes the instrumentation system used in acquiring the field measurements and presents the data-reduction procedure used to obtain results in meaningful forms. Sample measurements and results obtained on a number of vehicles are presented in the form of peak accelerations, power spectral densities, standard-deviation values, and histograms.

## DESCRIPTION OF MEASURING AND RECORDING SYSTEM

The measurement and recording of vibrations which affect passenger comfort present unique instrumentation requirements. The vibrations causing the greatest discomfort to human occupants in most transportation vehicles are generally characterized by low frequencies in the range from 0 to 25 Hz. (See ref. 9.) The basic requirements of a measuring and recording system are that the system be portable, self-contained, capable of measuring frequencies in the range from 0 to 25 Hz, and capable of measuring acceleration amplitudes in the range from 0.01 to 0.5g.

Two such systems have been developed and fabricated and are detailed in table I. Both systems are dynamically calibrated and are rechecked periodically to insure their accuracy. Both systems use the same linear transducers for measuring vibrations. However, system 1 (fig. 1) uses conditioning equipment consisting of voltage-controlled oscillators (VCO's) whose frequencies correspond to standard inter-range instrumentation group (IRIG) frequencies. The wiring diagram of measuring system 1 is shown in figure 2. A reference frequency of 12 500 Hz is multiplexed with the data channels as indicated in figure 3. This reference frequency is used during data recovery to eliminate any "wow" or "flutter" of the tape recorder. (See fig. 4.) A photograph of the measuring system (with its cover removed) is shown in figure 5. It should be noted that the VCO's in measuring system 1 are bypassed in system 2 since the signal conditioning is accomplished in the tape recorder.

The primary difference between the two systems is the tape recorder used for recording the data. System 1 utilizes a direct-record stereo tape recorder (fig. 1), whereas system 2 utilizes an FM tape recorder (fig. 6). It should be noted that the FM tape recorder used in system 2 is designed for recording data in field operations and as such can operate at temperatures between 0° and 49° C (32° and 120° F). The stereo tape recorder of system 1 is primarily designed for personal use and normal environments. Specifications and descriptions for both are given in table I.

The principal advantage of system 1 is its minimal weight and compactness. Its principal disadvantage is the additional time required in data retrieval where the data must be played back in real time to convert the IRIG multiplexed data to wide-band FM data. The main advantage of system 2 is that data retrieval can be accomplished two or four times faster than the data were originally recorded on wide-band FM tape. The FM tape recorder is less portable than the stereo tape recorder.

## PROCEDURE

### Data Acquisition

Prior to the installation of the instrumentation on a particular vehicle in the field, each accelerometer to be used is calibrated statically. Two voltage levels corresponding to 0 and 0.5g are generated and recorded on magnetic tape for each accelerometer. The 0.5g calibration is obtained by tilting the axis of the accelerometer 30° to the horizontal axis, as shown in figure 7. It is important to note that the steady-state 1g component that is always present in the vertical direction has been biased out electronically.

Occasionally two accelerometer packages are a test requirement, and together with cables and magnetic tapes, the versatility inherent with portability of the equipment is considerably reduced. The equipment in this situation must be packed in special reinforced suitcases, as shown in figure 8, and shipped commercially because the total weight of the equipment and luggage is approximately 712 N (160 lb). During operations, the accelerometer packages are located at several passenger stations in the vehicle, including either the center of gravity or an extreme end of the vehicle. Proper installation of the package requires that the package be leveled on a solid base, usually the metal floor beneath the carpet. This is accomplished by adjustable, steel, pointed legs attached to the bottom of the package. Figure 9 shows a typical installation on a train.

### Data Reduction

Large quantities of data are usually obtained in the course of making measurements of ride environments. A substantial amount of computer processing is required to convert the data into concise and meaningful forms. For example, high-speed train surveys

for track-improvement studies typically produce 20 hours of data. Rapid data-reduction procedures are therefore vitally necessary in the data-recovery phase of the ride-quality program which uses a high-speed digital computer.

During the data recovery for either system, the data are initially converted to wide-band FM carrier frequency (6.75 kHz) and rerecorded on 1-inch magnetic tape. A continuous time code is included during the rerecording of the data on this new tape. This time code becomes the primary reference in the analysis of the data. It is normally used to control the start and stop points of the digitizing equipment, and also for specifying sections of tape during computer processing.

An oscillograph record of all measurements complete with the synthetic time code and acceleration signals is obtained simultaneously with the 1-inch magnetic tape. Normally, in this process, the measurements are filtered by 14-Hz low-pass filters to eliminate any high-frequency interference from the low-frequency range of interest (0 to 10 Hz). The oscillograph record offers a quick-look visual display of the acceleration measurements and facilitates cross-checking the results of the digital data. Time codes are also translated from this record and used as reference points for selective data analysis. Standard digitizing techniques and procedures for applying calibration and engineering units are used to generate a digital tape. This, in turn, is the input for two different programs that provide statistical parameters describing the ride environment.

The two programs employed at the Langley Research Center for providing various statistical quantities of vibratory ride environments are a time series analysis (TSA) program and an exceedance program.

TSA program.- The TSA program is a general-purpose program used for the processing and analysis of random and stationary time-series data. (See ref. 10.) Up to 20 different channels of input data may be processed at one time. The program is capable of providing as many as 25 different statistical quantities such as the computation of the autocorrelations, cross-correlations, power spectral densities, and transfer functions. For the purpose of analyzing ride environments, the program outputs which have been proven of value include power spectral densities, histograms, standard deviations, mean values, and maximum and minimum acceleration magnitudes.

Exceedance program.- The exceedance program is primarily used for very rapid analysis of lengthy, continuous runs of random accelerations. The program computes statistical quantities in the form of exceedance counts of extended runs of data by equally dividing and evaluating the data over small increments of time or distance. For example, an analysis of a 3-hour run in 1-minute intervals can be performed in 17 minutes. The program outputs are in the form of computer printouts listing the number of times the magnitude of acceleration exceeds preselected values of acceleration for any period of time.

## DISCUSSION OF SAMPLE DATA

Emphasis on the ride-comfort-criteria program to date has been on instrumentation development and field measurements of vibration environments. Vibration measurements have been obtained on a significant number of vehicles, and the results have been compiled into a vehicle ride-quality data file at Langley Research Center. An inventory of ride environments in terms of statistical parameters has been compiled from the data processed through computer programs. To date, data have been obtained for automobiles, trains, commercial jet airliners, helicopters, and V/STOL aircraft. These field studies have been performed in an exploratory manner in an attempt to understand the cause-and-effect relationship of the vibration environment measured. The examples of data which follow are the result of computer outputs obtained by automated data-reduction procedures.

### Real-Time Data

An example of real-time data is shown in figure 10. This figure illustrates a sample of a vibration record measured on a STOL aircraft during a banked climb. The aircraft was a four-engine, turboprop, deflected-slipstream STOL aircraft having a maximum gross weight of 259 860 newtons (58 422 lb) and a 52-passenger capacity. The three traces in the figure show the vertical, longitudinal, and lateral acceleration in g (gravity) units as a function of time. The steady-state 1g component that is always present in the vertical direction has been biased out electronically. A considerable number of low-frequency, high accelerations (above 0.1g) occur in the vertical direction, as is typical of low-altitude flight, whereas more steady-state accelerations occur in the longitudinal and lateral directions. In any case, a higher frequency, probably associated with structural resonances of the airframe, appears to be superimposed on the fundamental frequency.

An example of some real-time data obtained on a train is shown in figure 11. These measurements were obtained over the front trucks of a railcar, at an average train speed of 177 km/hr (110 mph). Here, vertical, longitudinal, and lateral accelerations are shown, for about 16 seconds (approximately 805 m (1/2 mile)) on a curved track. The calibration factors for the three accelerometers are approximately the same for each channel. It is interesting to note that vibration is superimposed on the 0.105g steady-state lateral acceleration. The predominant frequency appears to be about 1 Hz. In the vertical direction, the peak acceleration magnitudes are about the same as those in the lateral direction. In the longitudinal direction, the vibration levels are very low. Again, as in the case of the STOL aircraft, the higher frequency which is indicated in all the traces probably results from structural resonances of the train.

### Power-Spectral-Density Data

To identify the dominant frequencies associated with the real-time data, the data are processed through a power-spectral-density (PSD) program where PSD analysis and plots are obtained for runs of any length. Figure 12 shows some examples of PSD plots of vertical motion measured at two locations on the railcar of a high-speed train. Vertical accelerations were measured over the trucks and at the center of the car. Note the different characteristics of the frequency response measured at the two locations. The peak power spectral density is greater over the trucks than at the center of the car. This should be expected inasmuch as the vibratory input from track to wheel to railcar occurs at this area. The dominant frequency of the ride is approximately 1 Hz. At the center of the car, considerable energy, indicative of the car bending frequency, is also concentrated around 9 Hz.

Figure 13(a) shows typical power-spectral-density plots of vertical and lateral motions measured on a STOL aircraft and a CTOL aircraft during cruise conditions. It should be noted that only representative examples are shown and that there were large differences in the operating characteristics between the aircraft. The STOL was cruising at an altitude of 610 meters (2000 feet) with a cruise speed of 371 km/hr (200 knots). The CTOL measurements were obtained at an altitude of 9150 meters (30 000 feet) with an average cruise speed of approximately 803 km/hr (434 knots). In the vertical direction, most of the vibratory energy is concentrated at frequencies of 0.1 Hz or lower for both aircraft. In the lateral direction, the energy levels are much lower than in the vertical direction, with the vibrational energy concentrated at 0.25 Hz for the STOL and below 0.1 Hz for the CTOL. Motions at frequencies less than 1 Hz are generally believed to produce symptoms of kinetosis (motion sickness), while higher frequency vibrations (e.g., the vibrational energy of the passenger trains) cause vibratory discomfort. It should be noted that the STOL aircraft in the lateral direction exhibited some energy in the frequency range 5 to 9 Hz, as shown in figure 13(b). The PSD analysis can be varied to permit detailed investigation over any frequency range of interest.

### Acceleration-Magnitude Data

The magnitude of the vibratory accelerations measured during field tests can be described by a number of parameters, such as peak values, total rms values, standard-deviation values, histograms, and acceleration exceedance counts. The statistical parameters are obtained with the use of a computer. Figures 14(a) and 14(b) show plots of the computed values of standard deviation and rms magnitude, respectively, for six different flight conditions plus taxiing measured on a CTOL aircraft. The flight conditions include (1) runway take-off, (2) lift-off, (3) climbout, (4) cruise, (5) approach, and (6) touchdown. In addition, the corresponding VGH flight parameters of airspeed and altitude are also



shown in the figures. The standard deviation, shown in figure 14(a), is a statistical measure of the magnitude of vibration about the mean, whereas the rms magnitude, shown in figure 14(b), is a statistical measure of the total magnitude of vibration measured including the mean value. The agreement between standard deviation and rms magnitude is good for all the flight conditions, except for very smooth cruise conditions, as established by engineering judgment. The standard-deviation values obtained for two smooth cruise conditions are approximately the same at a minimal value of 0.005g. However, the rms magnitude parameters computed for the same conditions are substantially larger than the standard-deviation values and, in fact, higher than the rms magnitude obtained for one taxi condition. A comparison of these two parameters for smooth cruise conditions indicates that the standard deviation is a better statistical parameter in qualitatively defining ride vibrations over large periods of time.

Figure 15 shows a sample of the percentage of time that specified vibratory acceleration levels are exceeded during cruise conditions for the STOL and CTOL aircraft. The data for the STOL aircraft are shown as bands that represent the limits of measurements obtained at the front and rear areas of the STOL during six different periods of time. In the lateral direction, the greater portion of the bounded area represents accelerations measured at the rear of the airplane.

Exceedance counts can be displayed in another form such as in the computer print-out shown in figure 16. These data were obtained from vibration measurements on a high-speed train obtained during a track improvement program undertaken in collaboration with the U.S. Department of Transportation. Since time was recorded during analysis and only for reference, and since the recording proceeded four times as fast as the data were obtained, the times indicated in figure 16 are one-fourth of the actual elapsed time.

The interval samples in the listing are the total samples between mileposts. Mileposts are listed at the far right of the figure. The three values listed (0.050, 0.060, and 0.150) at the top of the columns, are preselected g-level thresholds. The numbers listed in the three columns are the percentages of the time that these g levels are exceeded. For example, the number 4.4 (first number in 0.050 column) indicates that of the 3218 samples of acceleration between the previous milepost and milepost 251, 4.4 percent of these samples had values greater than 0.05g. Similar sets of numbers are shown for exceedance values in the vertical direction where the selected g values are 0.080, 0.100, and 0.150. Asterisks are program printed beside any number greater than 5 percent. Also, various city names are program printed beside selected numbers. For example, the code 240 causes Wilmington to be printed and indicates that the train is at the incoming station marker, and 241 indicates that the train is at the outgoing station marker. From data such as these, particularly bad sections of track which contribute to a rough ride can be identified.

Histograms are another form of data presentation. The histograms indicate the manner in which the number of acceleration occurrences measured within a specified magnitude interval are distributed throughout the range of possible values of the magnitude. Figure 17 shows sample histograms measured on a helicopter during cruise conditions at 167 km/hr (90 knots). These plots show high density distributions about values other than the mean value, which is the result of a discrete-frequency (blade-passage-frequency) input. As a matter of interest, a pure sine-wave input would result in a U-shaped histogram symmetric about the mean value.

Figure 18 shows sample histograms measured on STOL and CTOL aircraft during cruise conditions. These plots indicate a high probability density about the mean values, which is indicative of a random process.

### CONCLUDING REMARKS

An application of aerospace instrumentation and data-reduction techniques for measuring and interpreting ride vibration environments is presented as part of an overall ride-comfort-criteria program at the Langley Research Center. Special attention is placed on the utility of a portable system for measuring and recording low-frequency accelerations. Data-reduction methods and sample vibration measurements are also discussed.

The data show that the vibrational environments measured for various types of vehicles tend to be random in nature, and are adequately evaluated with the use of a digital high-speed computer.

The vibration-data parameters considered to be of value in defining ride quality include peak-acceleration magnitudes, power-spectral-density distributions, rms magnitudes, histograms, and exceedance counts. Preliminary studies indicate that the standard deviation is an important statistical parameter in qualitatively defining ride vibrations.

Langley Research Center,  
National Aeronautics and Space Administration,  
Hampton, Va., April 24, 1972.

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TABLE I.- MEASURING AND RECORDING SYSTEMS

(a) Measuring systems

System	Measurements	Transducer type	Power source	Conditioning equipment	Encoder
1	Three mutually perpendicular accelerations	Kistler servo accelerometers	Mercury batteries, 30-hr useful life or nickel-cadmium chargeable batteries	Voltage-controlled oscillators with center frequencies of 2300, 3900, 5400, 10 500 (for encoder), and 12 500 Hz (for reference)	Self-powered unit with binary-coded decimal (BCD) digits from 0 to 999
2	Same as above	Same as above	Same as above	None required	Same as above

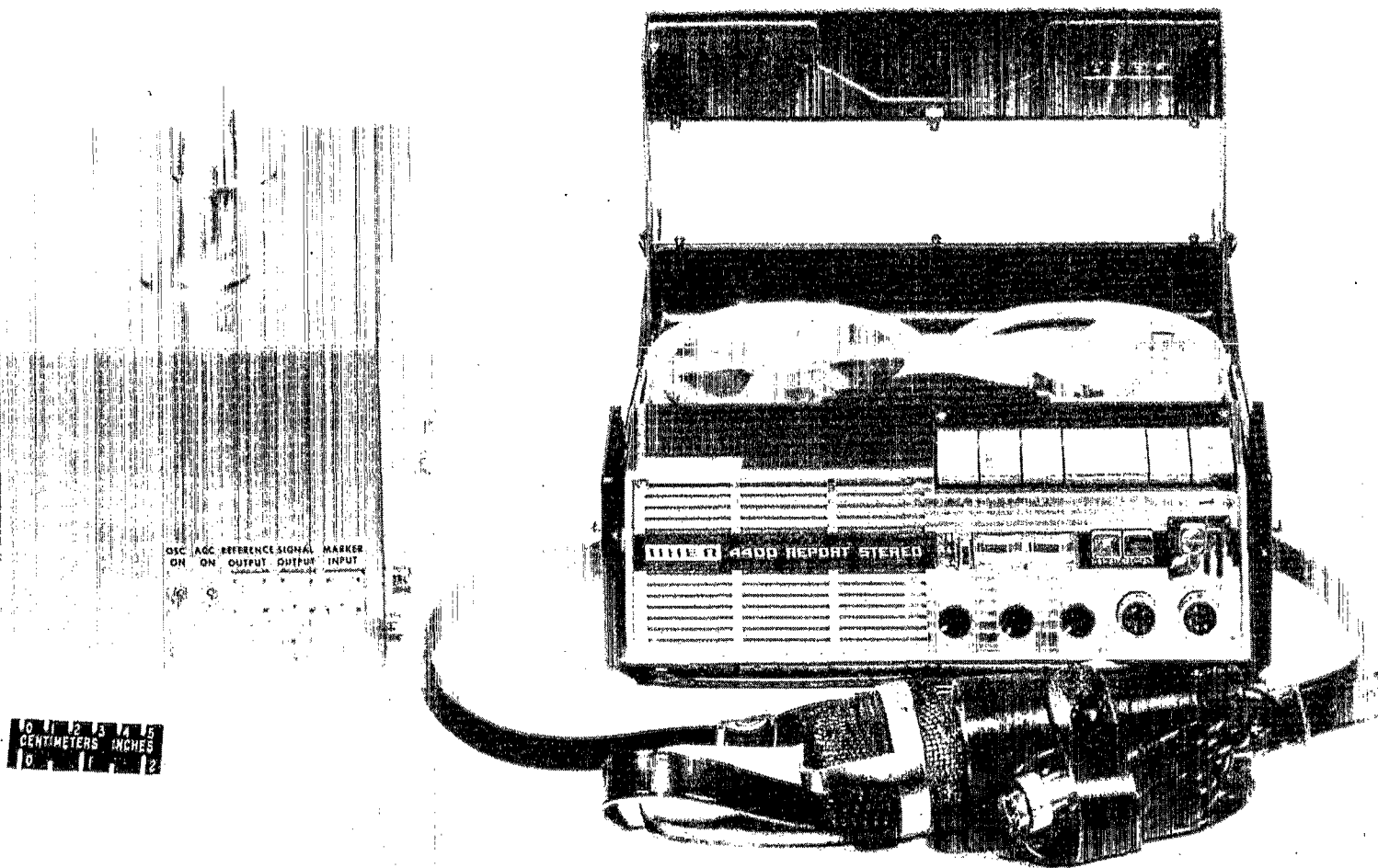
(b) Recording systems

System	Tape recorder	Reel and tape size	Weight	Power source	Wow and flutter	Speed, ips	Frequency response, Hz	Center frequency, Hz
1	Uher model 4400, two-channel, direct record	5-in. reel, $\frac{1}{4}$ -in. magnetic tape, 1800 ft long	35.6 N (8 lb)	Nickel-cadmium batteries, 6-hr duration and chargeable	0.2% at $7\frac{1}{2}$ ips	15/16 $1\frac{7}{8}$ * $3\frac{3}{4}$ $7\frac{1}{2}$	3 000 6 500 10 500 14 000	Not applicable
2	Lockheed model 417, seven-channel, FM plus voice track	7-in. reel, $\frac{1}{2}$ -in. magnetic tape, 1800 ft long	129 N (29 lb)	Nickel-cadmium batteries, $1\frac{1}{2}$ -hr duration and chargeable	0.4% at $7\frac{1}{2}$ ips	$1\frac{7}{8}$ * $3\frac{3}{4}$ $7\frac{1}{2}$	0 to 625 0 to 1 250 0 to 2 500	3 375 6 750 10 125

(c) Overall measuring and recording systems

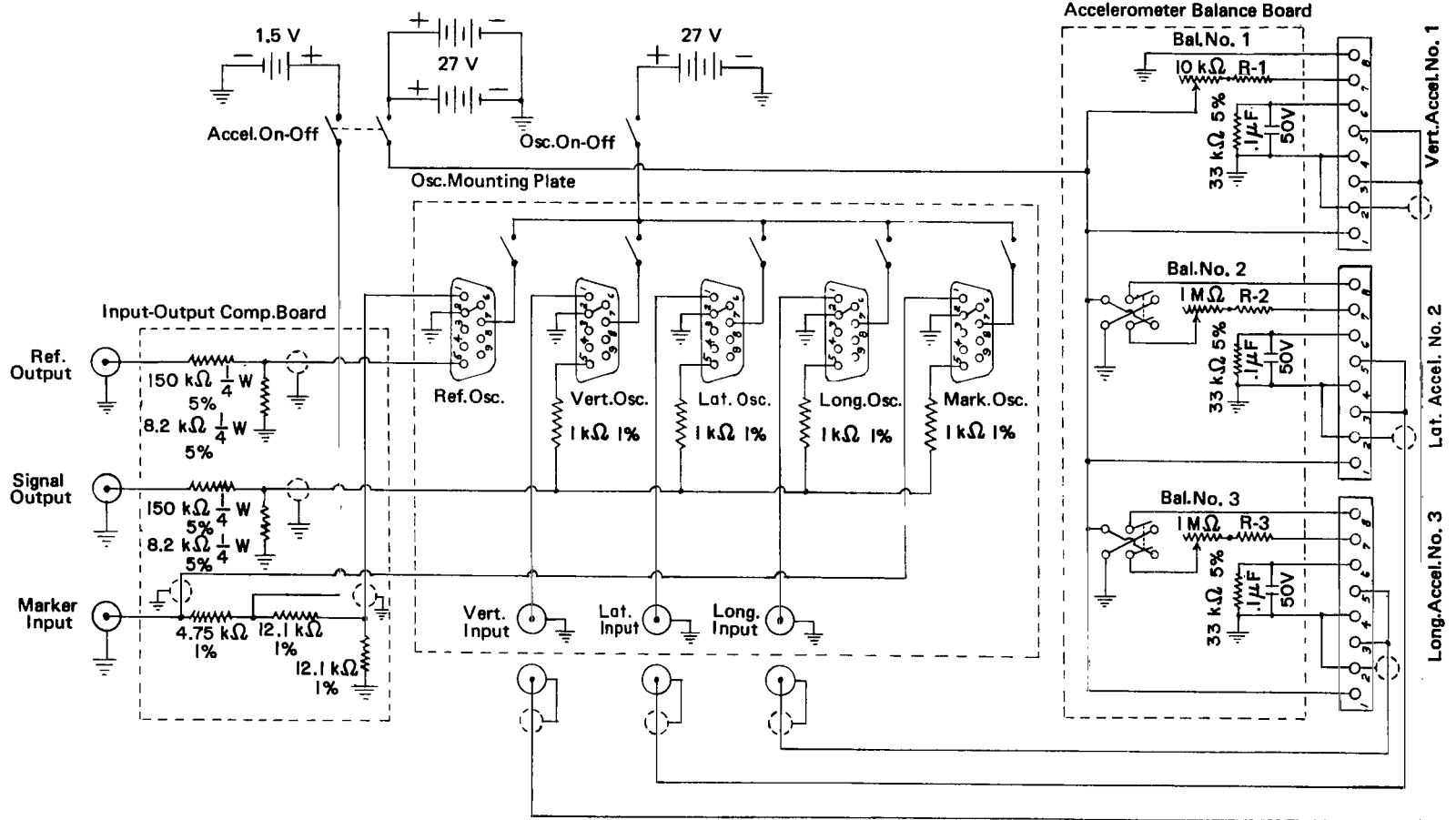
System	Maximum data-channel capacity	Accuracy	Reliability	Weight
1	10 channels (IRIG standards) plus voice track	$\pm 4\%$	Fair	125 N (28 lb)
2	Seven channels plus voice track	$\pm 2\%$	Excellent	218 N (49 lb)

\*Recording speed normally used.



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Figure 1.- Data-acquisition and recording system for system 1.



Resistors R-1, R-2, R-3, Determined Experimentally

Figure 2.- Wiring diagram of measuring system 1.

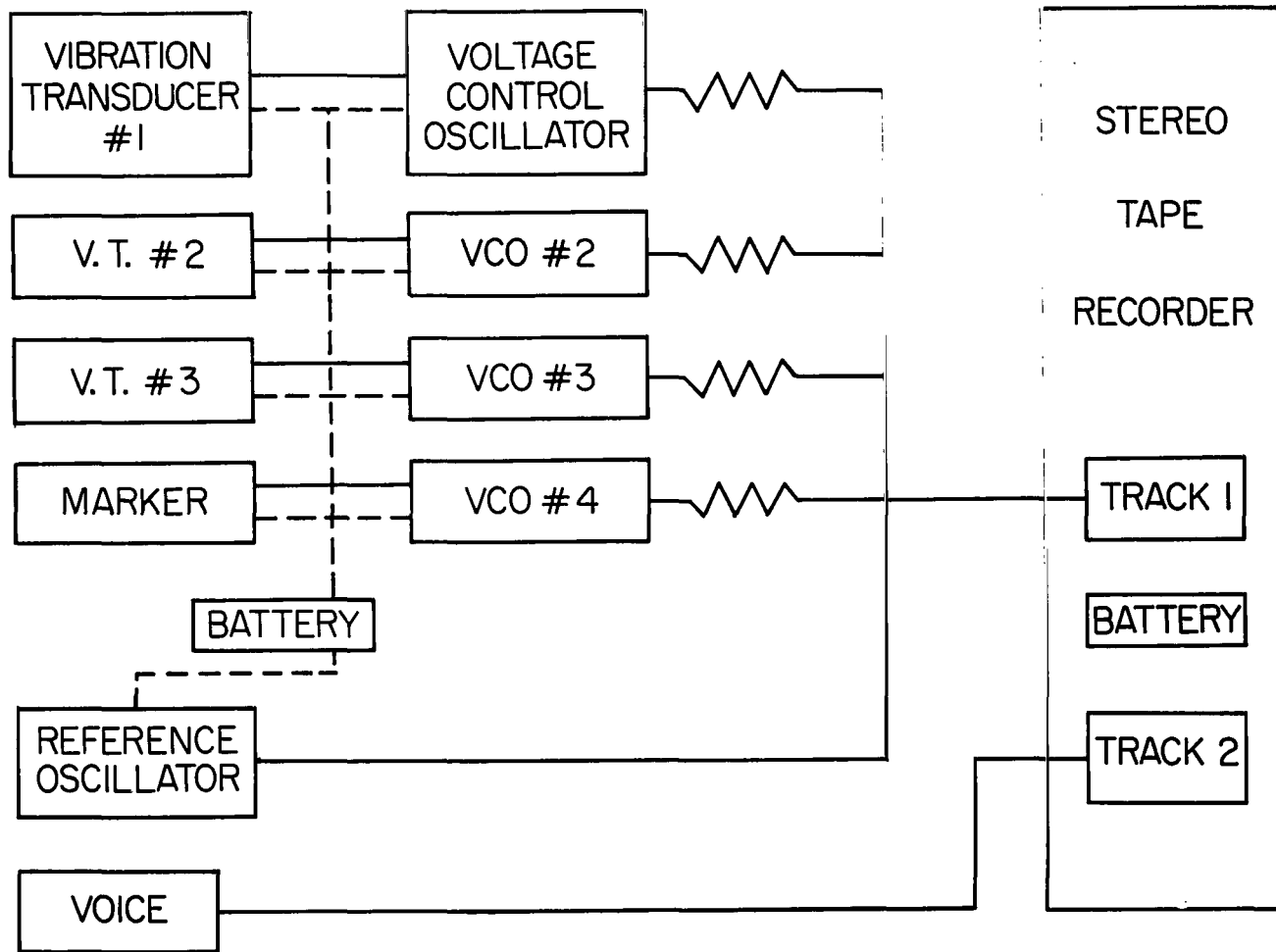


Figure 3.- Functional diagram of measuring and recording system.

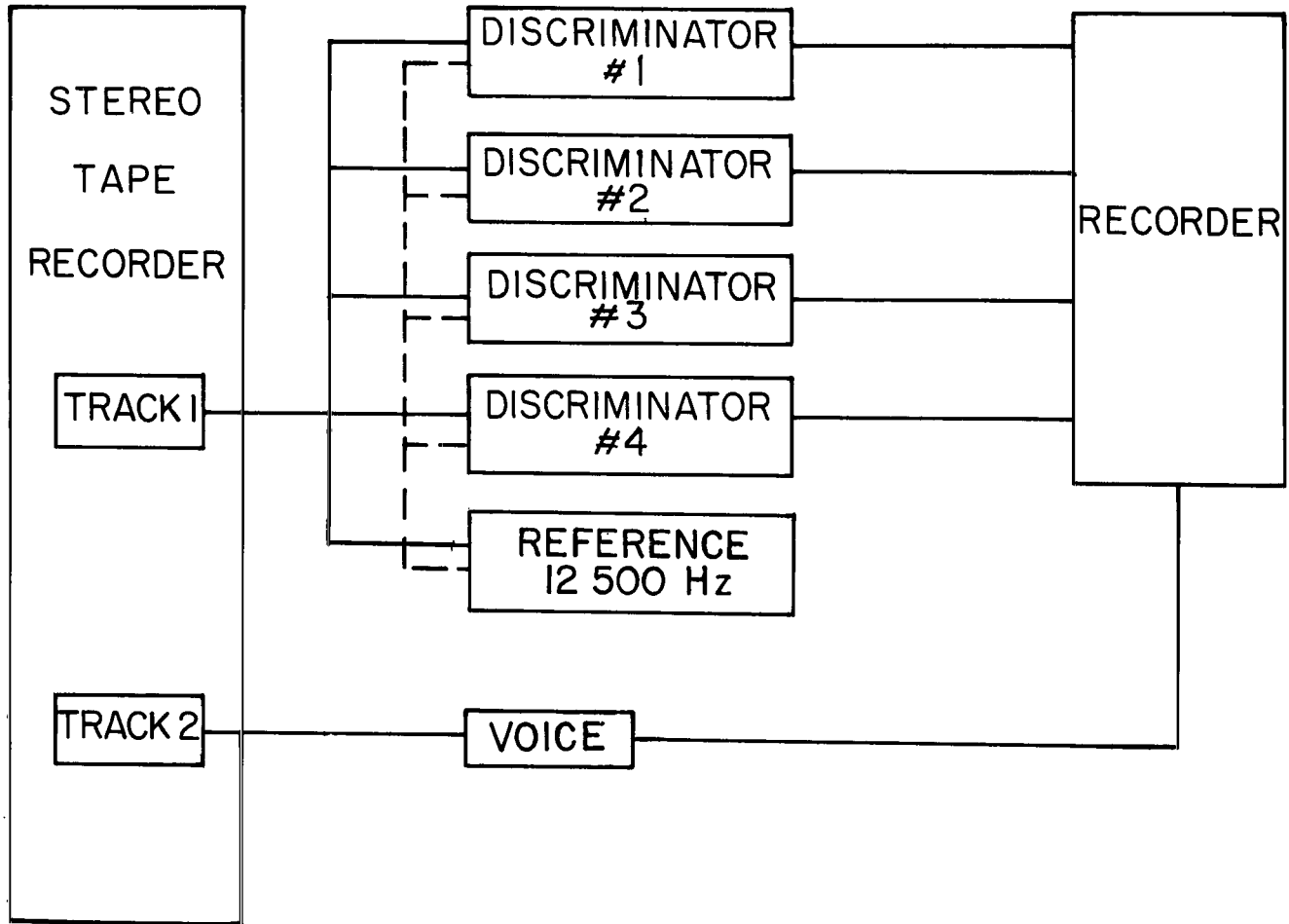


Figure 4.- Functional diagram of the data recovery system.



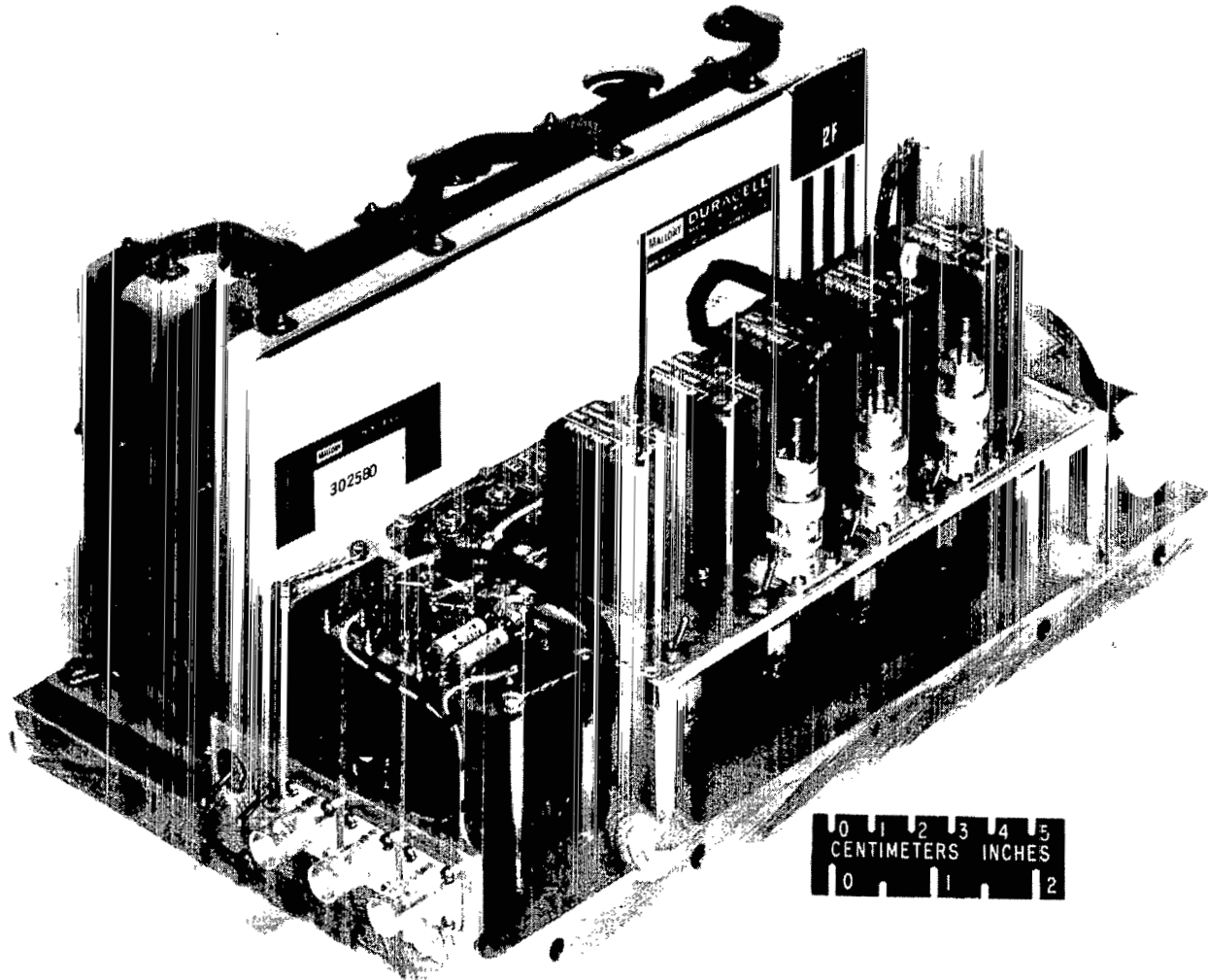
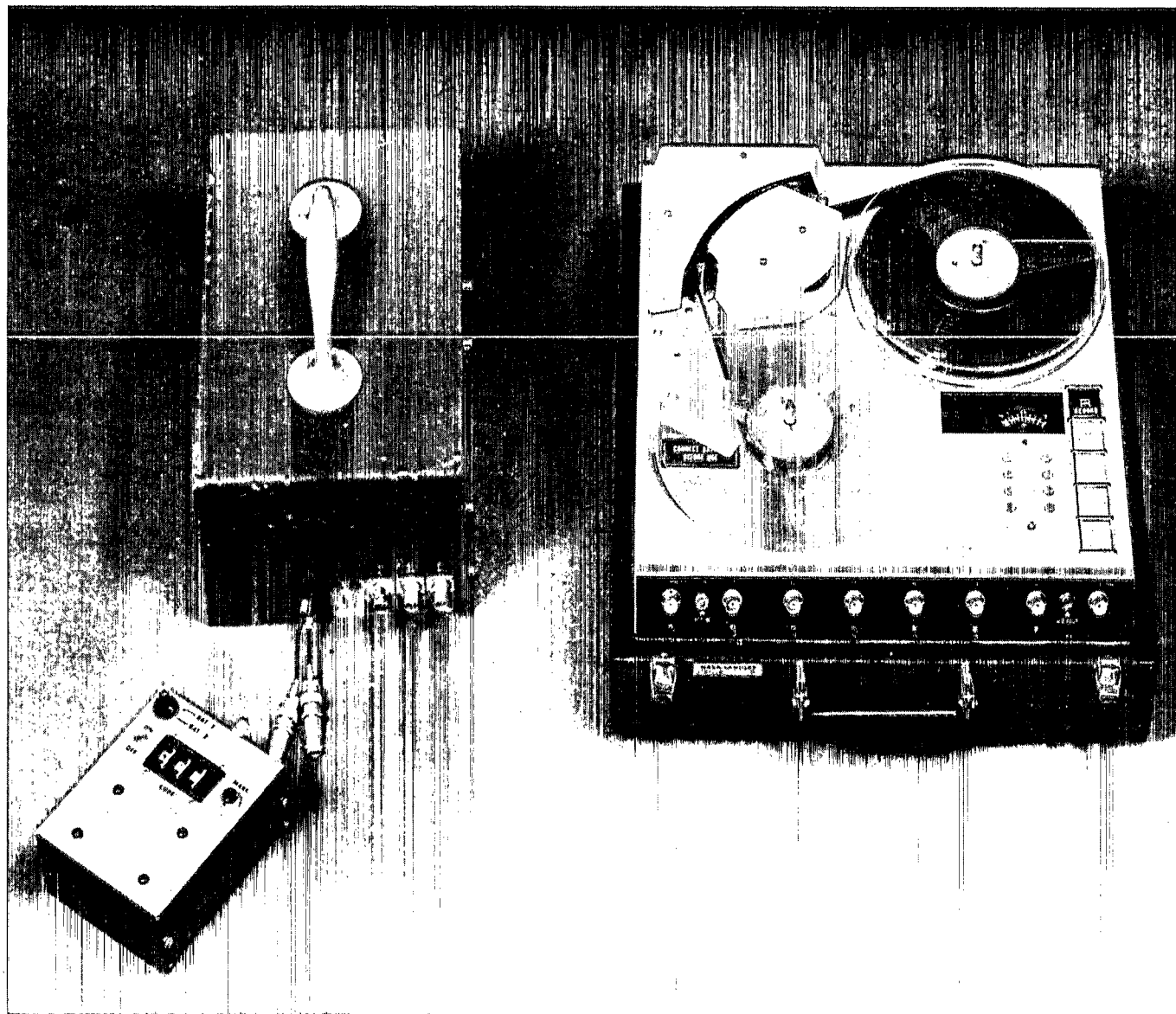


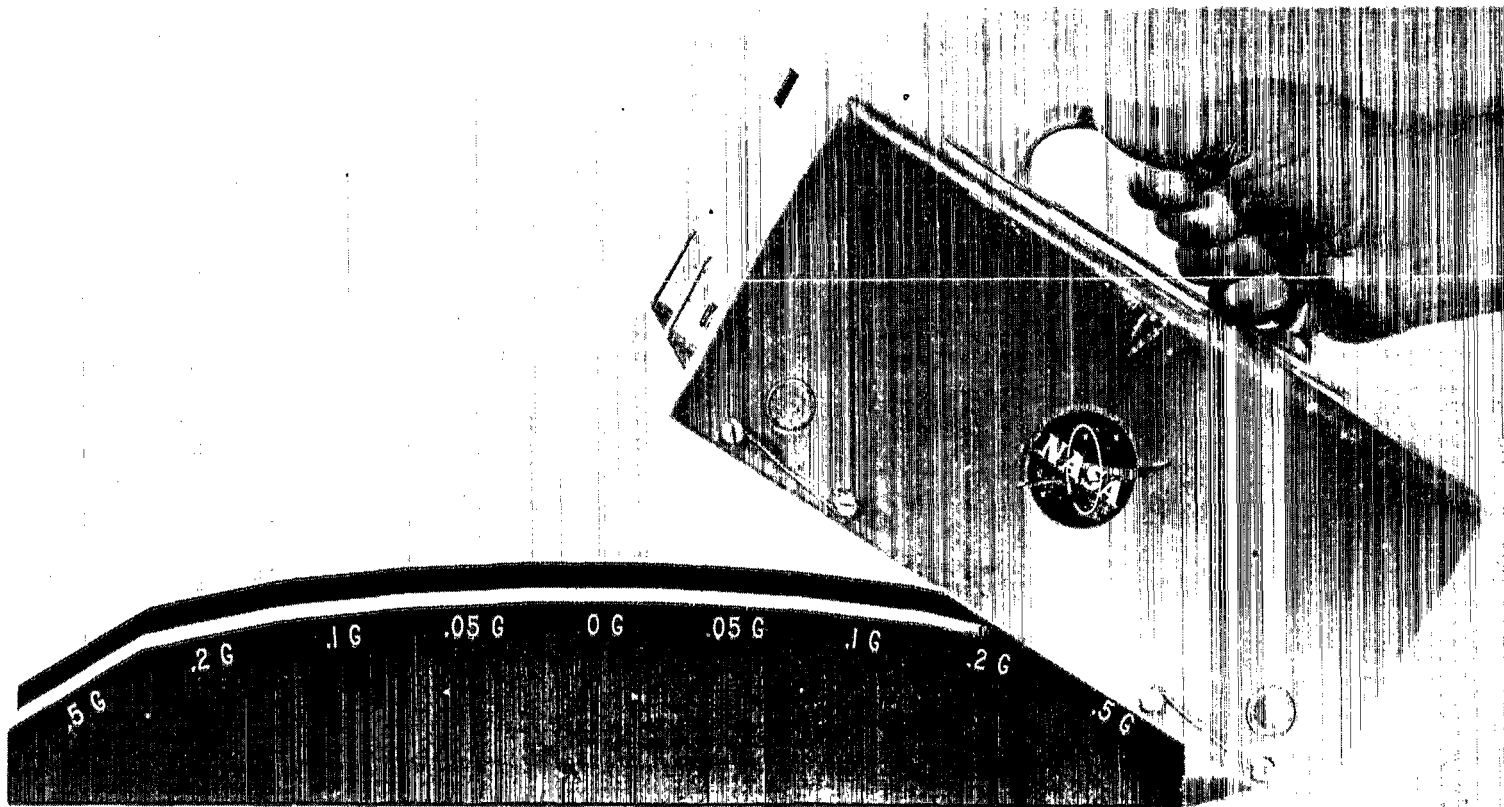
Figure 5.- Portable measuring system with cover removed.

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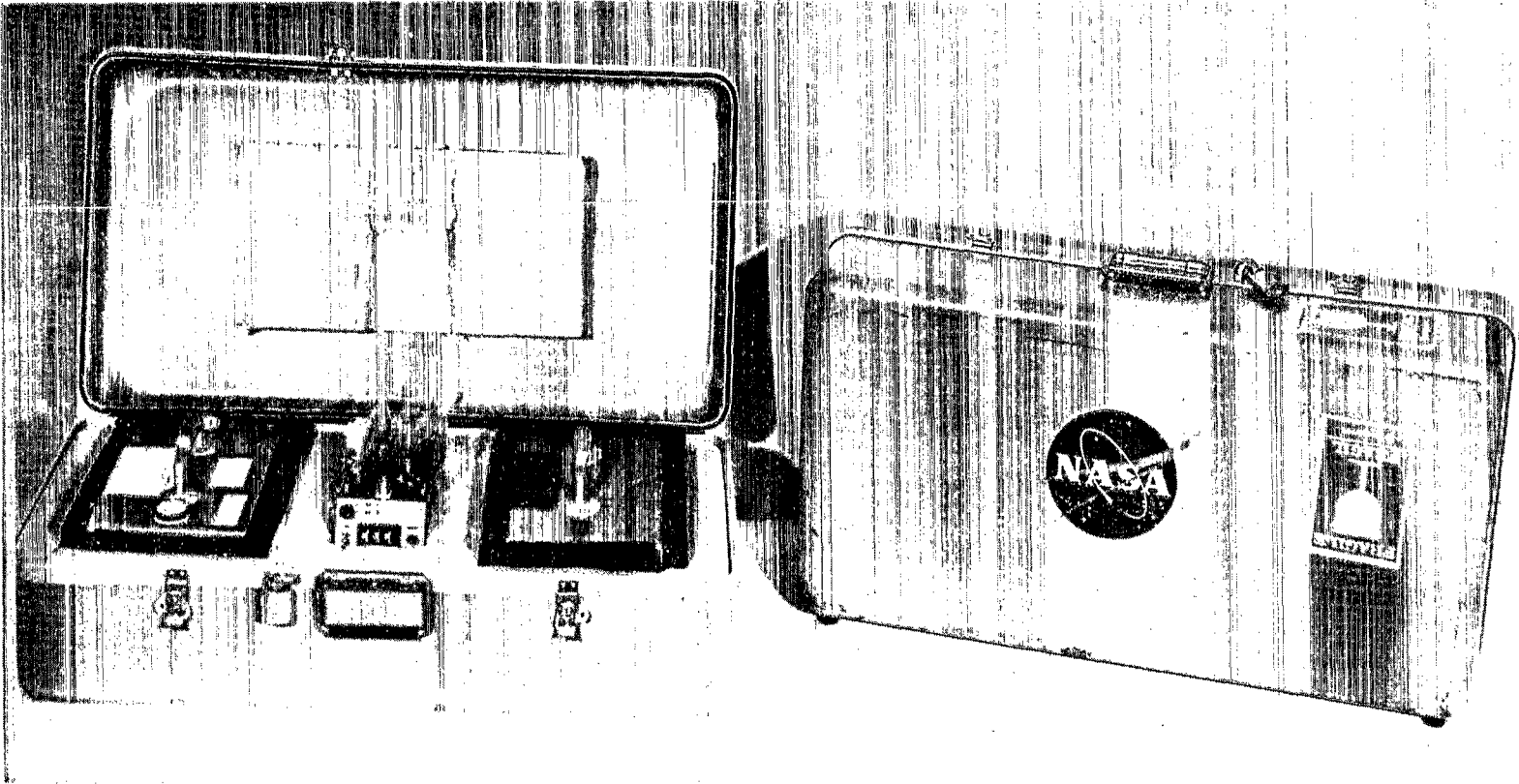
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Figure 6.- Data-acquisition and recording system 2.



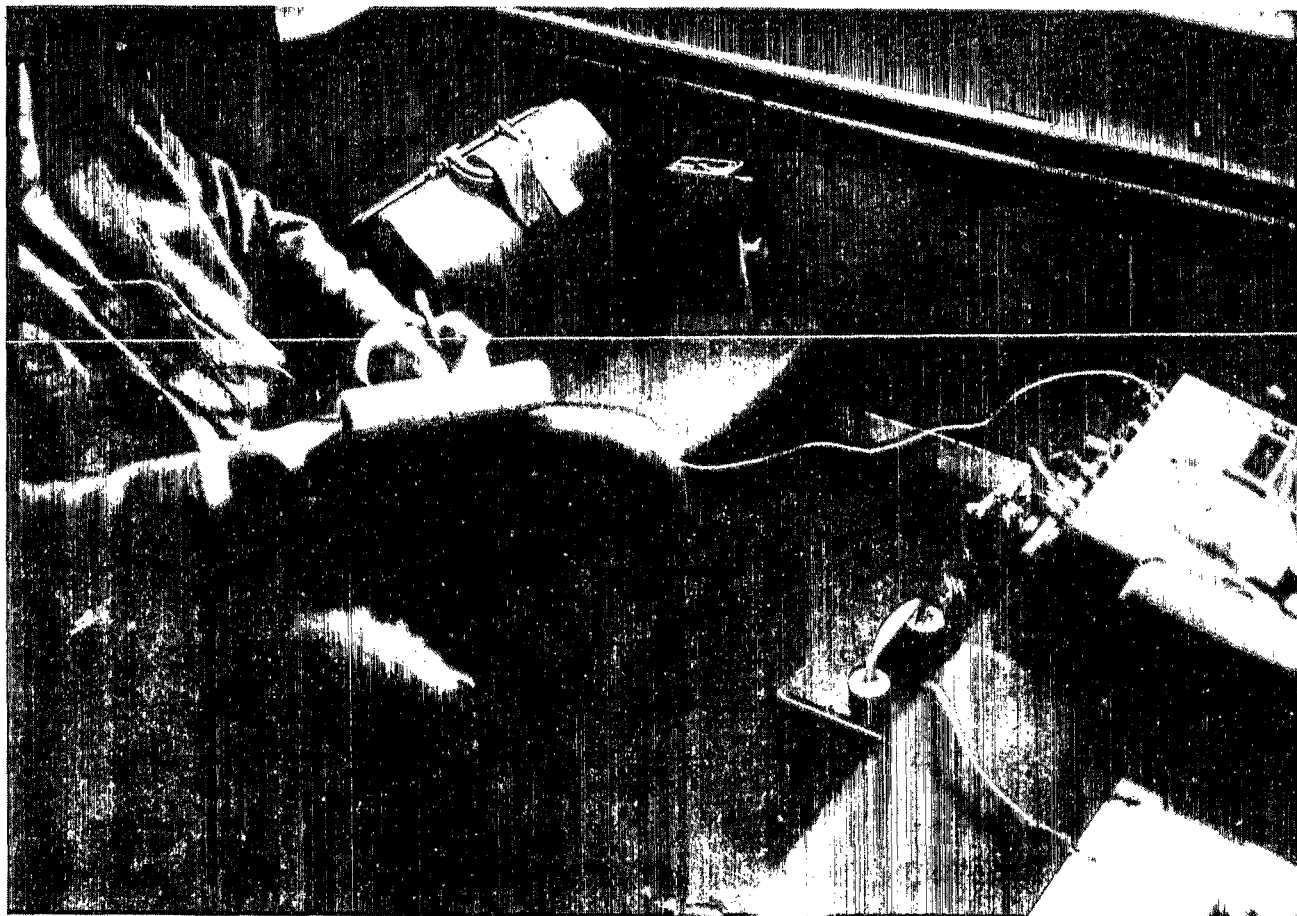
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Figure 7.- Calibration of accelerometer in lateral direction for 0.5g.



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Figure 8.- Luggage for packaging instrumentation to be transported via commercial carriers.



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Figure 9.- Typical setup on a train.

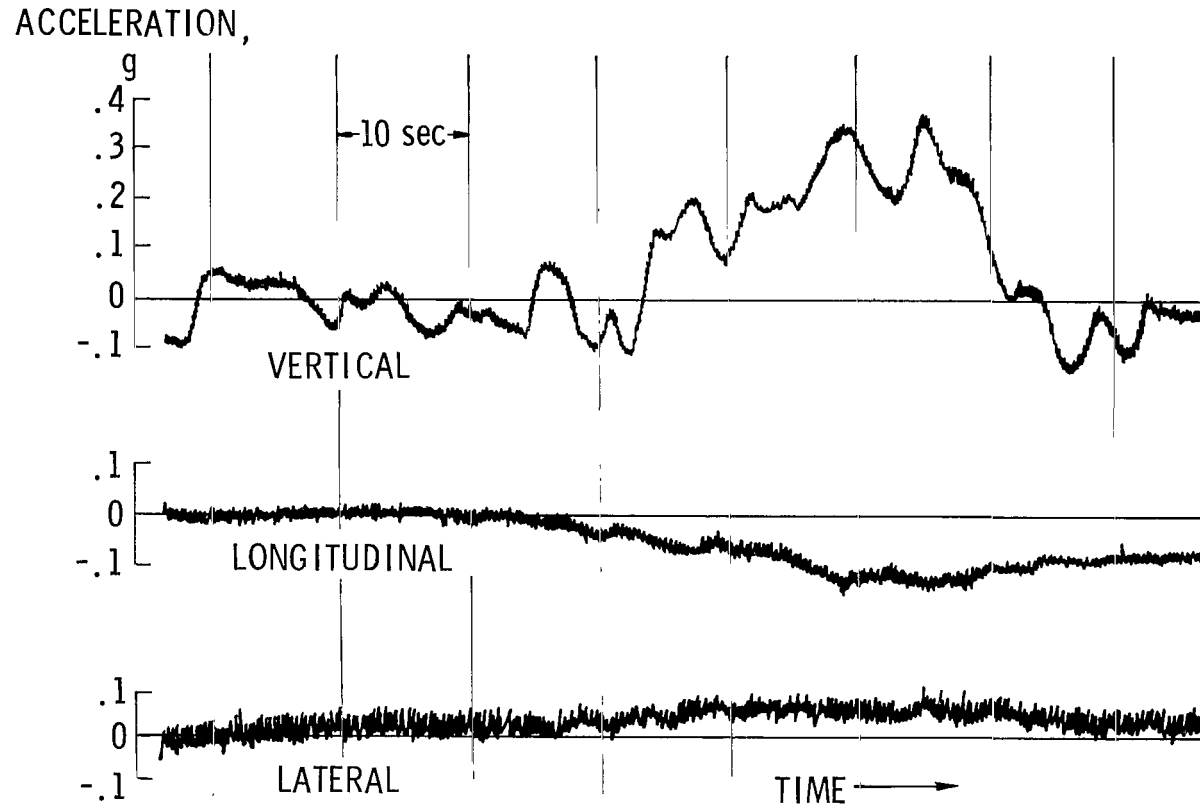
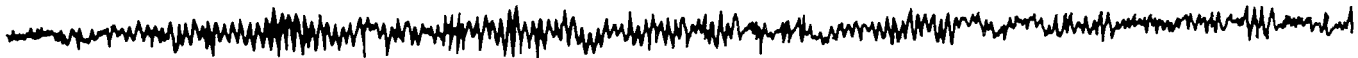


Figure 10.- Sample vibrations measured on STOL aircraft during 25° banking maneuver at 389 km/hr (210 knots).



VERTICAL ACCELERATION



LONGITUDINAL ACCELERATION

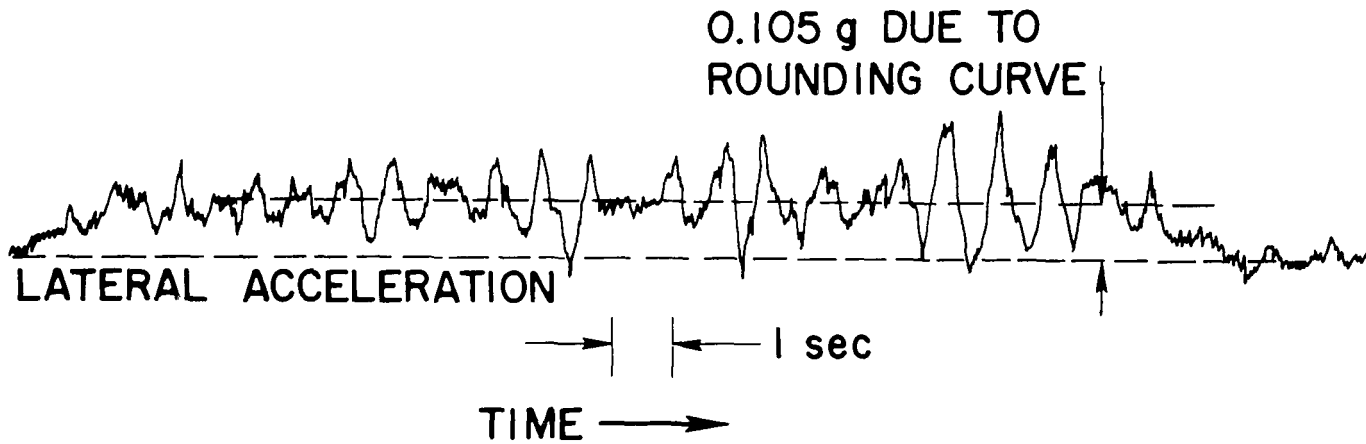


Figure 11.- Sample vibration record measured over front trucks of railcar on curve.

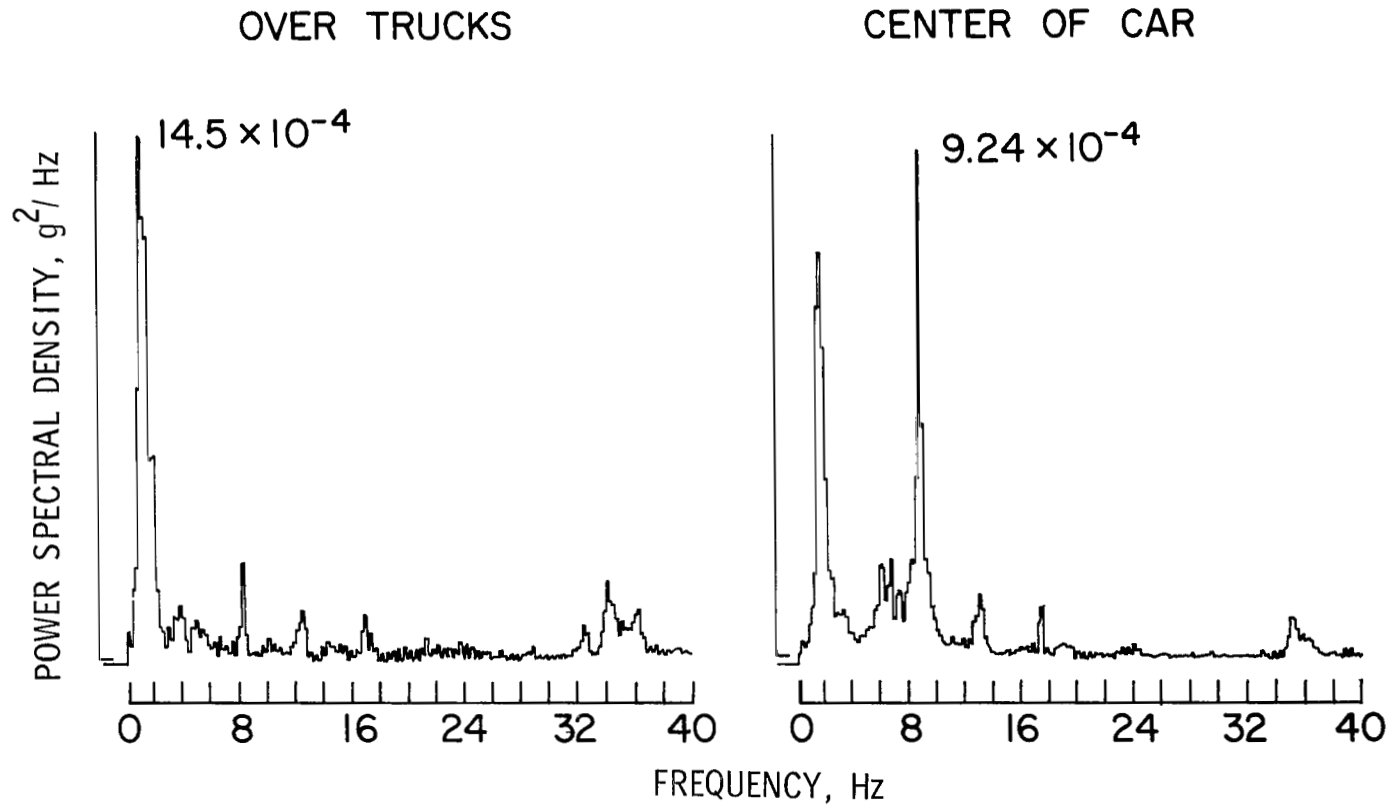
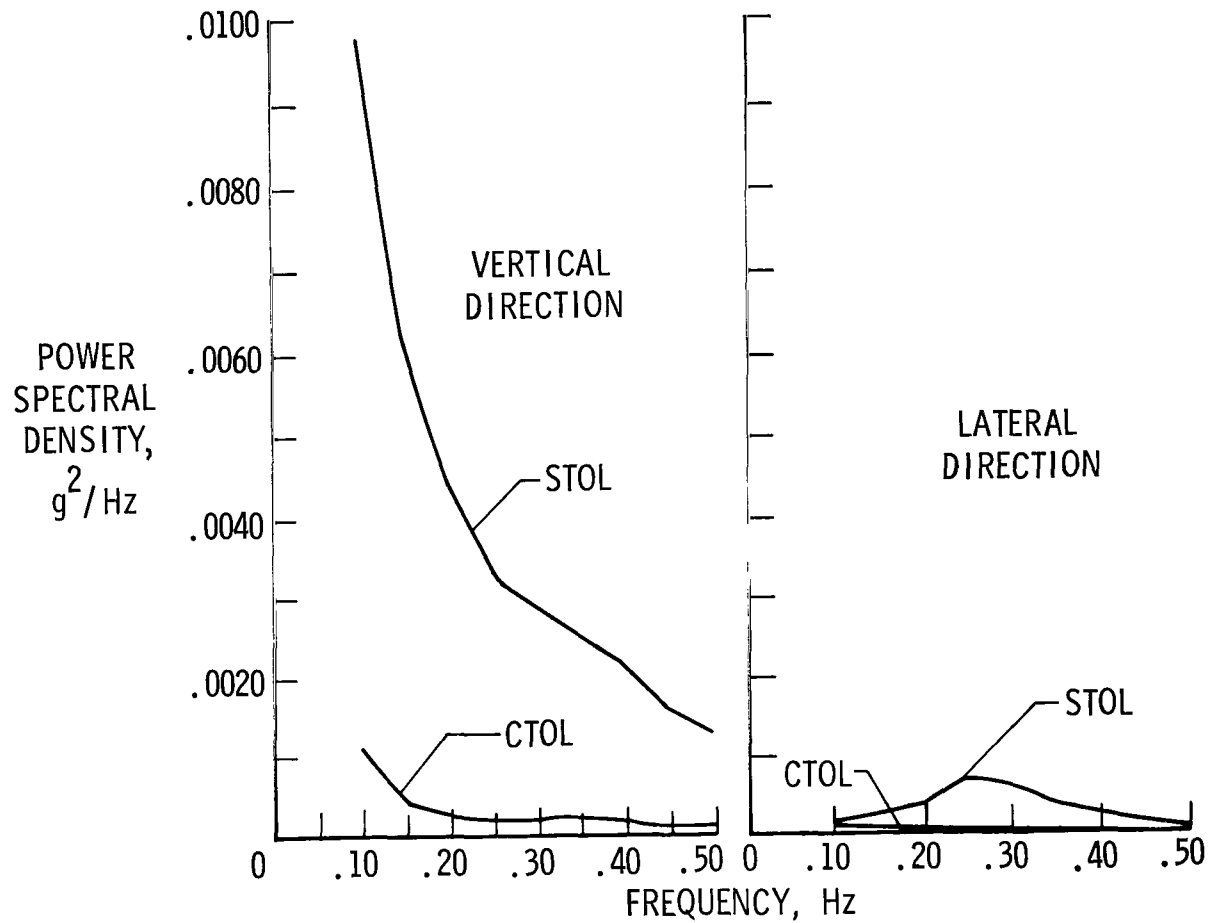


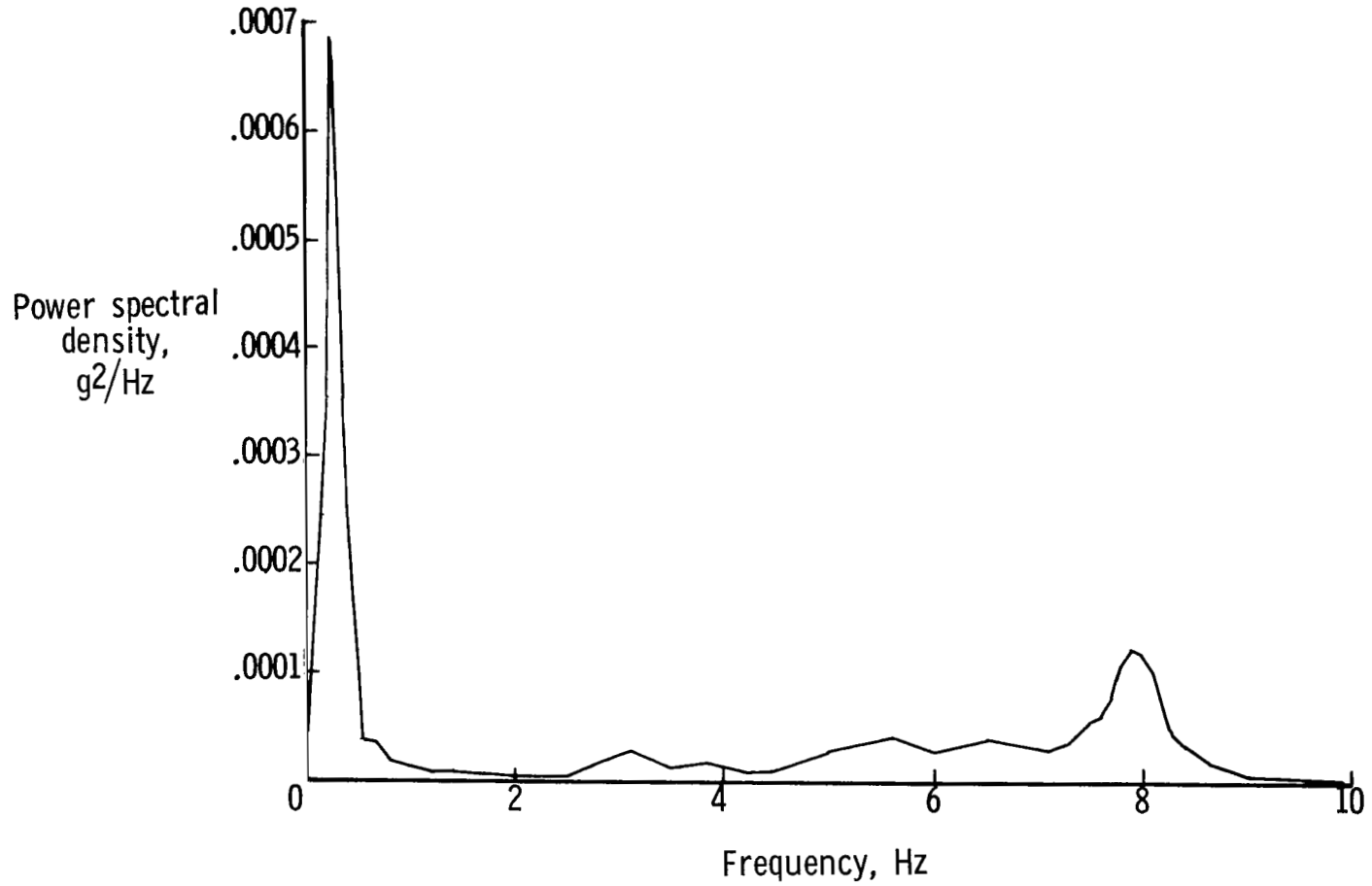
Figure 12.- Sample power-spectral-density plots of vertical motion measured on a high-speed train at a speed of 164 km/hr (102 mph).





(a) Vertical and lateral directions for both aircraft. Frequency, 0.1 to 0.5 Hz.

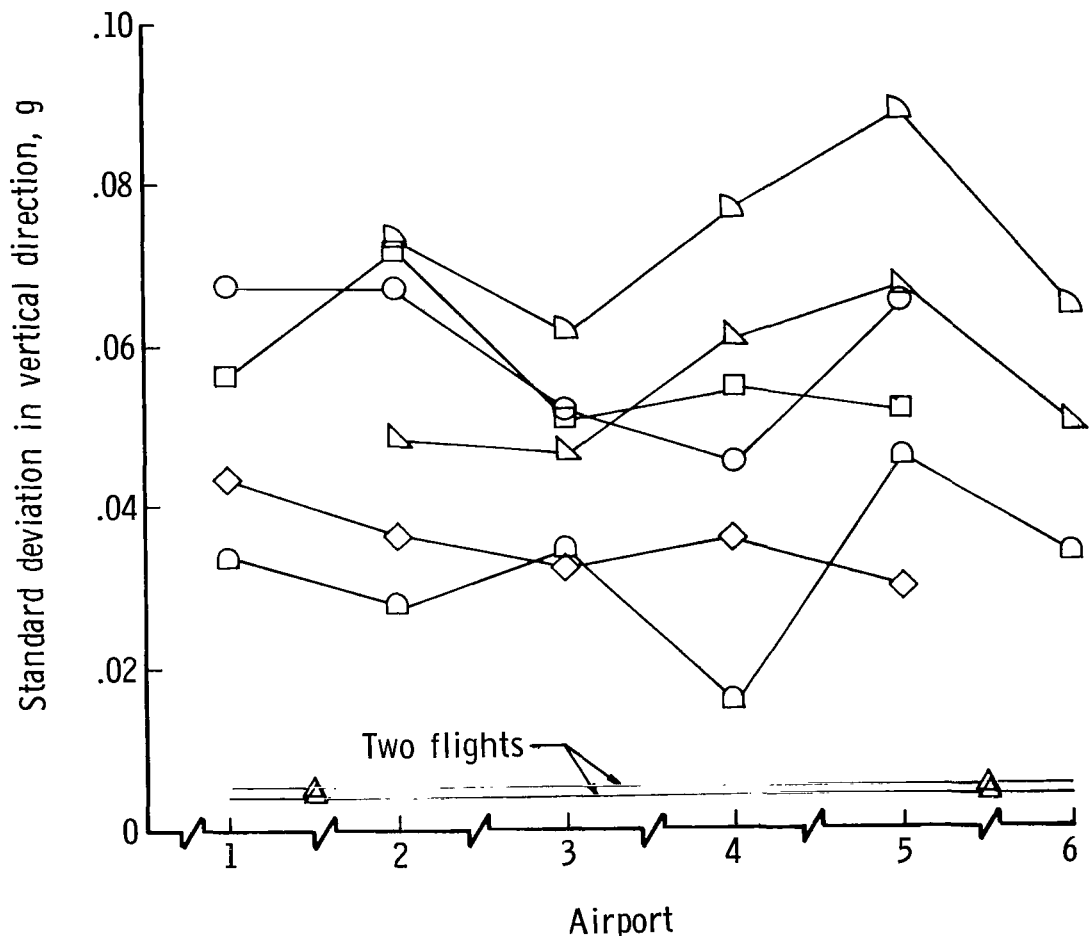
Figure 13.- Sample power spectral density plots measured on STOL and CTOL aircraft in cruise conditions.



(b) Lateral direction for STOL aircraft. Frequency, 0.1 to 10 Hz.

Figure 13.- Concluded.

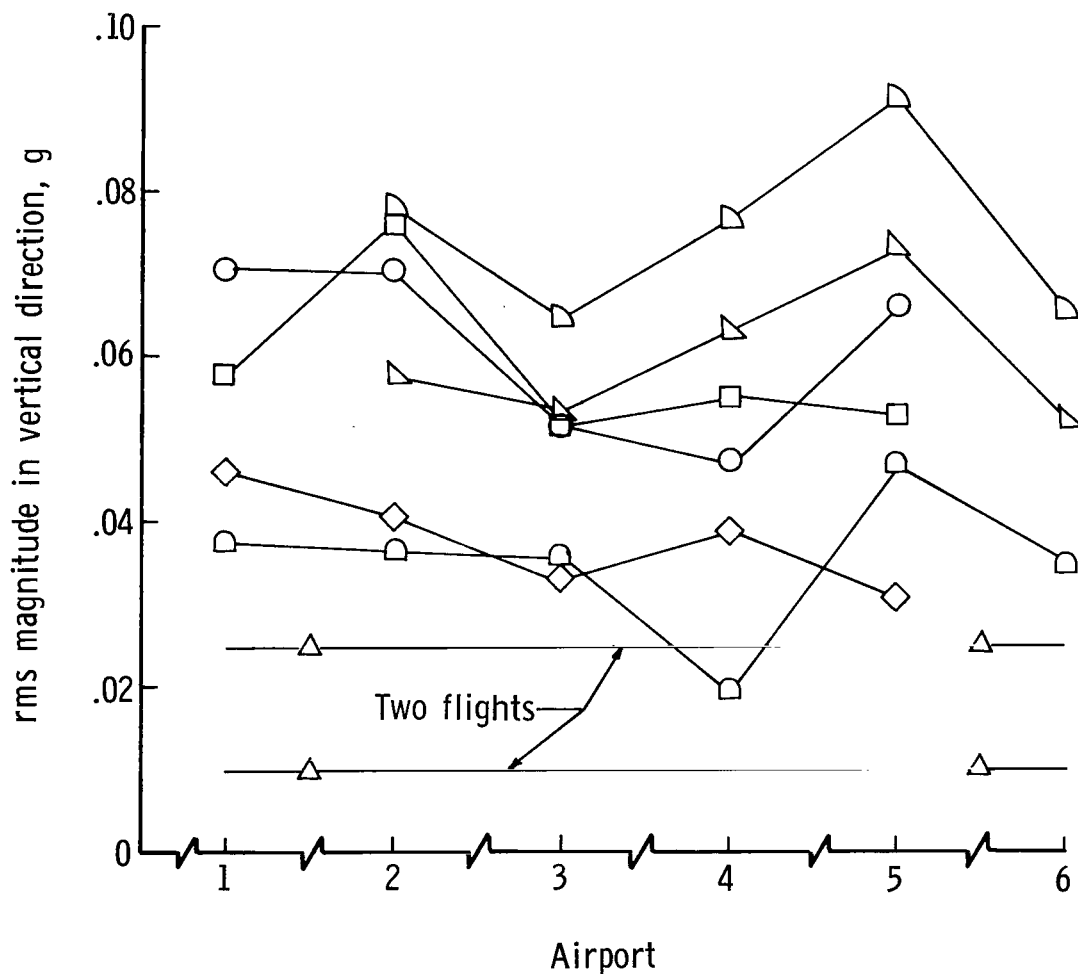
Symbol	Flight condition	Average speed, km/hr (knots), at -		Altitude, km (ft), at -	
		Start	End	Start	End
○	Take-off roll	0	245 (132)	-----	-----
□	Lift-off	245 (132)	552 (298)	Ground	3.45 (11330)
◇	Climbout	552 (298)	658 (355)	3.39 (11130)	8.08 (26500)
△	Smooth cruise	584 (315)	584 (315)	9.59 (31450)	9.59 (31450)
▽	Approach	663 (358)	237 (128)	8.11 (26605)	Ground
▷	Touchdown and roll	237 (128)	0	-----	-----
◻	Taxi	37 (20)	37 (20)	-----	-----



(a) Standard deviation.

Figure 14.- Computed values of standard deviation and rms magnitude of accelerations obtained on a CTOL aircraft for six different flight conditions and taxi at six airports.

Symbol	Flight condition	Average speed, km/hr (knots), at -		Altitude, km (ft), at -	
		Start	End	Start	End
○	Take-off roll	0	245 (132)	-----	-----
□	Lift-off	245 (132)	552 (298)	Ground	3.45 (11330)
◇	Climbout	552 (298)	658 (355)	3.39 (11130)	8.08 (26500)
△	Smooth cruise	584 (315)	584 (315)	9.59 (31450)	9.59 (31450)
▽	Approach	663 (358)	237 (128)	8.11 (26605)	Ground
▷	Touchdown and roll	237 (128)	0	-----	-----
◻	Taxi	37 (20)	37 (20)	-----	-----



(b) rms magnitude.

Figure 14.- Concluded.

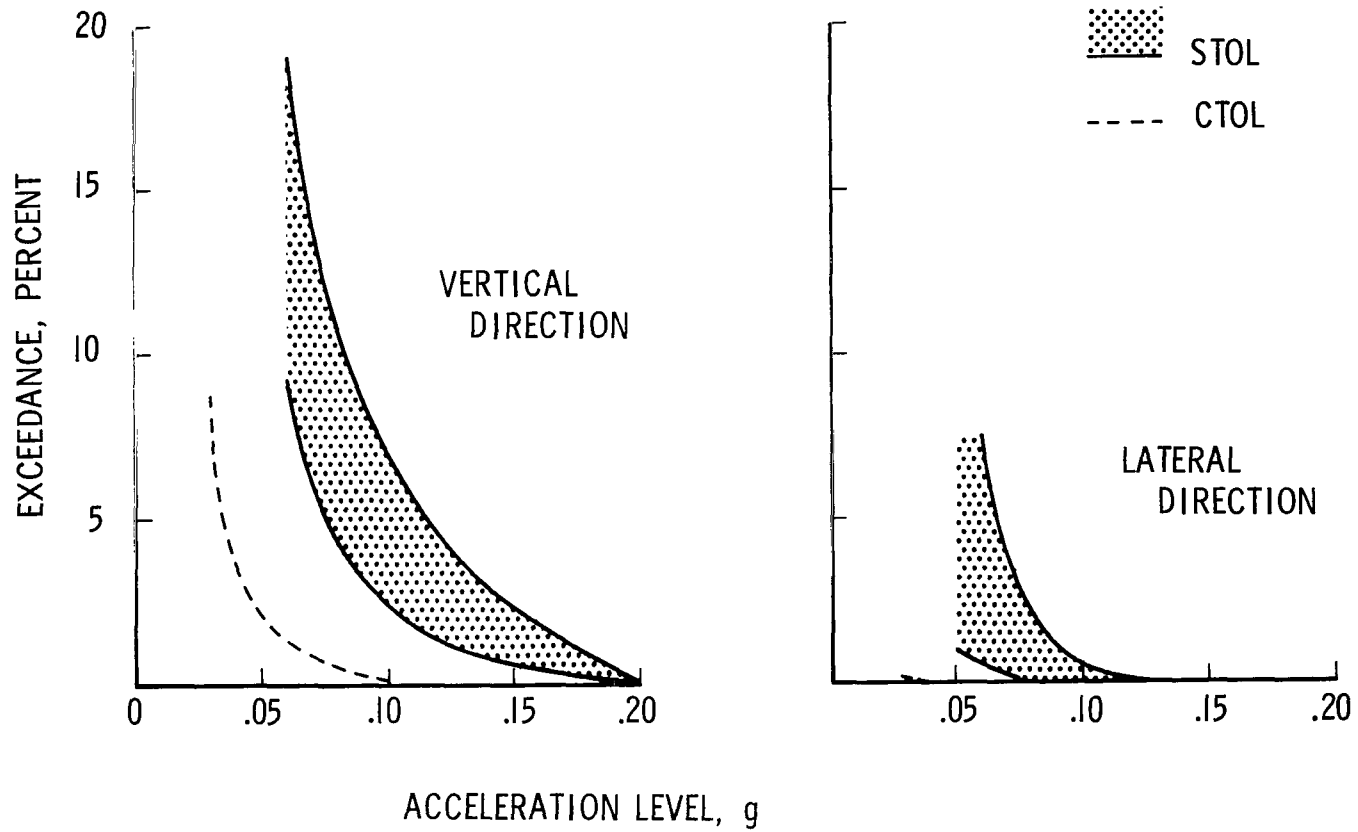


Figure 15.- Percentage of time a given acceleration level is exceeded during cruise conditions.

## NASA-DOT TRACK RIDING QUALITY PROGRAM

DATE 3 / 19 / 70		SYSTEM 2		.1		TRAIN NO. 107		
CAR NO. 851		(NUMBER 1 OF 6 CARS IN TRAIN)						
TIME	INTERVAL SAMPLES	LATERAL			VERTICAL			MILE POST
		.050	.060	.150	.080	.100	.150	
11:48:50.65	3218	4.4	4.1	2.5	3.5	3.2	2.4	251 PHILADELPHIA
11:49:30.15	7900	4.2	2.6	.1	6.1 *	2.3	.3	3
11:50: 8.10	7590	1.3	.8	0.0	10.7 *	3.9	.1	5
11:50:20.96	2572	.2	0.0	0.0	9.1 *	3.8	.4	6
11:50:33.77	2562	1.8	1.2	0.0	7.9 *	4.0	.4	7
11:50:45.08	2261	.5	.3	0.0	2.5	.1	0.0	8
11:50:54.15	1815	.9	.4	0.0	3.1	.6	.1	9
11:51: 2.96	1762	6.1 *	3.6	.5	4.7	1.4	0.0	10
11:51:11.78	1764	5.2 *	2.7	0.0	4.5	1.1	.1	11
11:51:20.79	1802	11.7 *	7.3 *	0.0	6.4 *	2.8	.2	12
11:51:29.49	1740	26.1 *	19.6 *	.3	14.3 *	7.6 *	1.9	13
11:51:38.55	1811	13.7 *	8.7 *	.1	21.8 *	13.5 *	3.6	14
11:51:47.41	1773	12.8 *	9.6 *	.2	19.6 *	12.1 *	3.4	15
11:51:56.55	1828	3.7	1.5	0.0	10.8 *	5.3 *	1.3	16
11:52:13.23	3336	2.2	.8	0.0	9.7 *	3.8	.3	17
11:52:28.20	2994	.3	.0	0.0	1.0	.4	0.0	18
11:52:38.22	2003	2.8	1.6	0.0	1.7	.7	.1	19
11:52:45.77	1511	15.9 *	12.5 *	.5	6.0 *	2.1	.3	20
11:52:53.53	1551	11.5 *	9.6 *	.1	5.6 *	2.6	.6	21
11:53: 1.39	1573	7.7 *	5.0 *	.4	5.6 *	2.5	.3	22
11:53:10.23	1767	16.5 *	12.0 *	.6	9.2 *	4.8	.3	23
11:53:20.15	1985	.5	.2	0.0	.5	.1	0.0	24
11:53:28.98	1766	3.1	1.9	0.0	3.3	1.5	.5	25
11:53:40.20	2243	8.6 *	6.0 *	.2	19.7 *	11.9 *	3.7	26
11:53:53.48	2657	3.3	2.2	0.0	9.3 *	4.5	.8	240 WILMINGTON
11:54: 2.99	1902	2.1	1.1	.2	2.5	.5	0.0	754
11:54:16.38	2677	6.3 *	6.0 *	4.1	5.5 *	5.0 *	4.2	241 WILMINGTON
11:54:39.06	4536	3.1	1.3	0.0	24.9 *	15.9 *	4.6	28
11:54:50.73	2335	5.7 *	3.5	0.0	9.3 *	4.1	.4	29

\* 5 percent or greater.

Figure 16.- Sample of computer printout for acceleration exceedance counts.

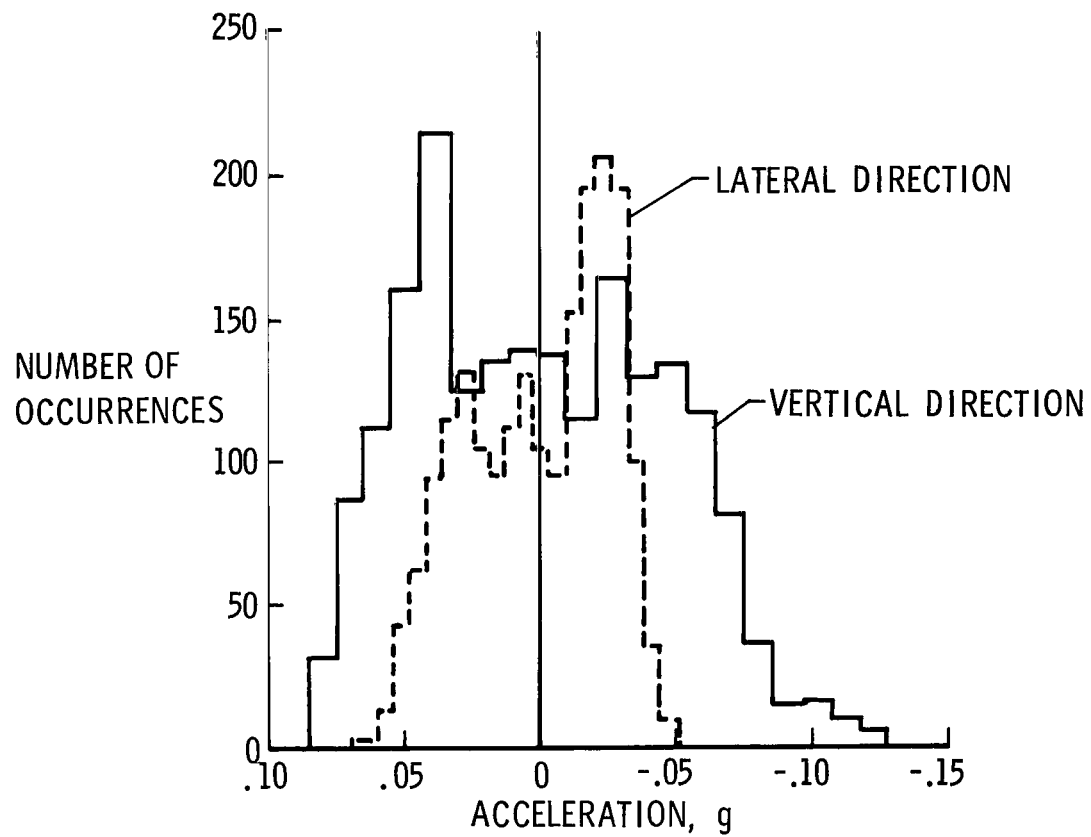


Figure 17.- Sample histograms for helicopter measured during cruise conditions at 167 km/hr (90 knots).

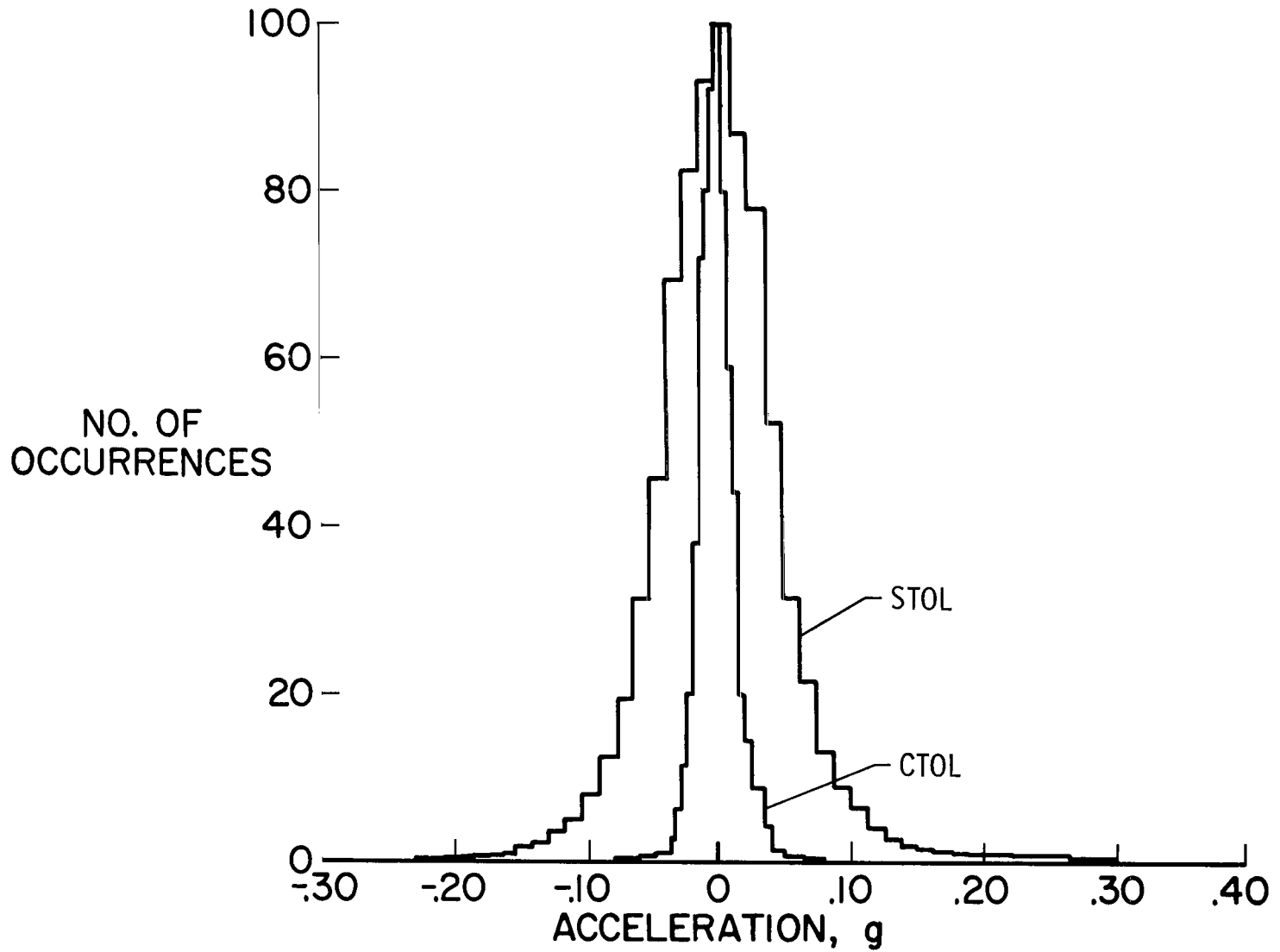


Figure 18.- Sample histograms for STOL and CTOL aircraft measured during cruise conditions. Vertical direction.





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