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STANDARD RIDE QUALITY
DATA REDUCTION PACKAGE

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EXECUTIVE SUMMARY

This report deals with software programs and analysis relating to vehicle ride vibration data. Descriptions of the digitizing procedure, both theoretical and operational, are given. A detailed description of the analysis procedures is given, along with detailed descriptions of the software. These include both flow charts and subroutines.

TABLE OF CONTENTS

1.0 INTRODUCTION

The software described in this manual is specifically designed to evaluate the ride quality of a vehicle from acceleration data. The data consist of vehicle vibrations that are recorded in analog form. The data collection system is primarily the FRA/ENSCO portable ride quality package. Data are recorded with six accelerometers, three of which are linear. Figure 1 shows the relationship of the measurement axes.

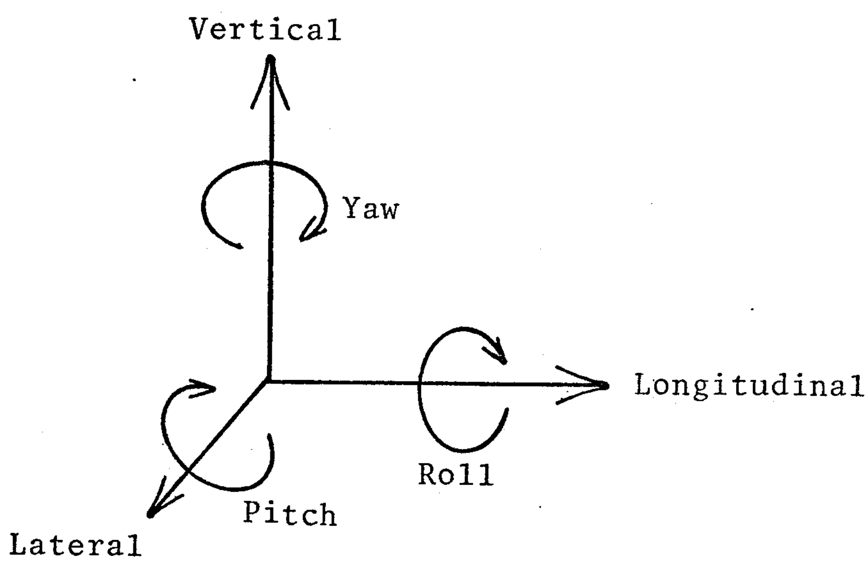


Figure 1. Relationship of Measurement Axes

The data collection system consists of a magentic tape recorder, a signal conditioning and coding unit, and an accelerometer package. The accelerometer package details are given in Table 1. The sigal conditioning and coding unit converts the current output of each accelerometer to a proportional signal voltage suitable for recording. The unit provides metering for signal monitoring and calibration. This unit also contains batteries, and associated charging and regulator circuits which provide power to the system if AC power is not available. The magnetic tape recorder accommodates eight channels of data. Six channels are used for recording accelerometer signals. The seventh channel is used for a multiplex recording of two external data signals, an internally generated digital annotation, and a reference signal. A channel is provided for voice annotation. More detail on this instrumentation is given in Appendix F.

Table 1. Accelerometer Characteristics

Accelerometer	Full Scale
Vertical	± 1 g
Longitudinal	± 1 g
Lateral	± 1 g
Yaw	± 1 rad/sec^2
Roll	± 5 rad/sec^2
Pitch	± 1 rad/sec^2

The software described in this report is used on the Raytheon minicomputer RDS-500 system. This inhouse computer has three tape drives, a card reader, a printer/plotter, a disc pack, and a teletype. A descriptive flow chart of the system is shown in Figure 2.

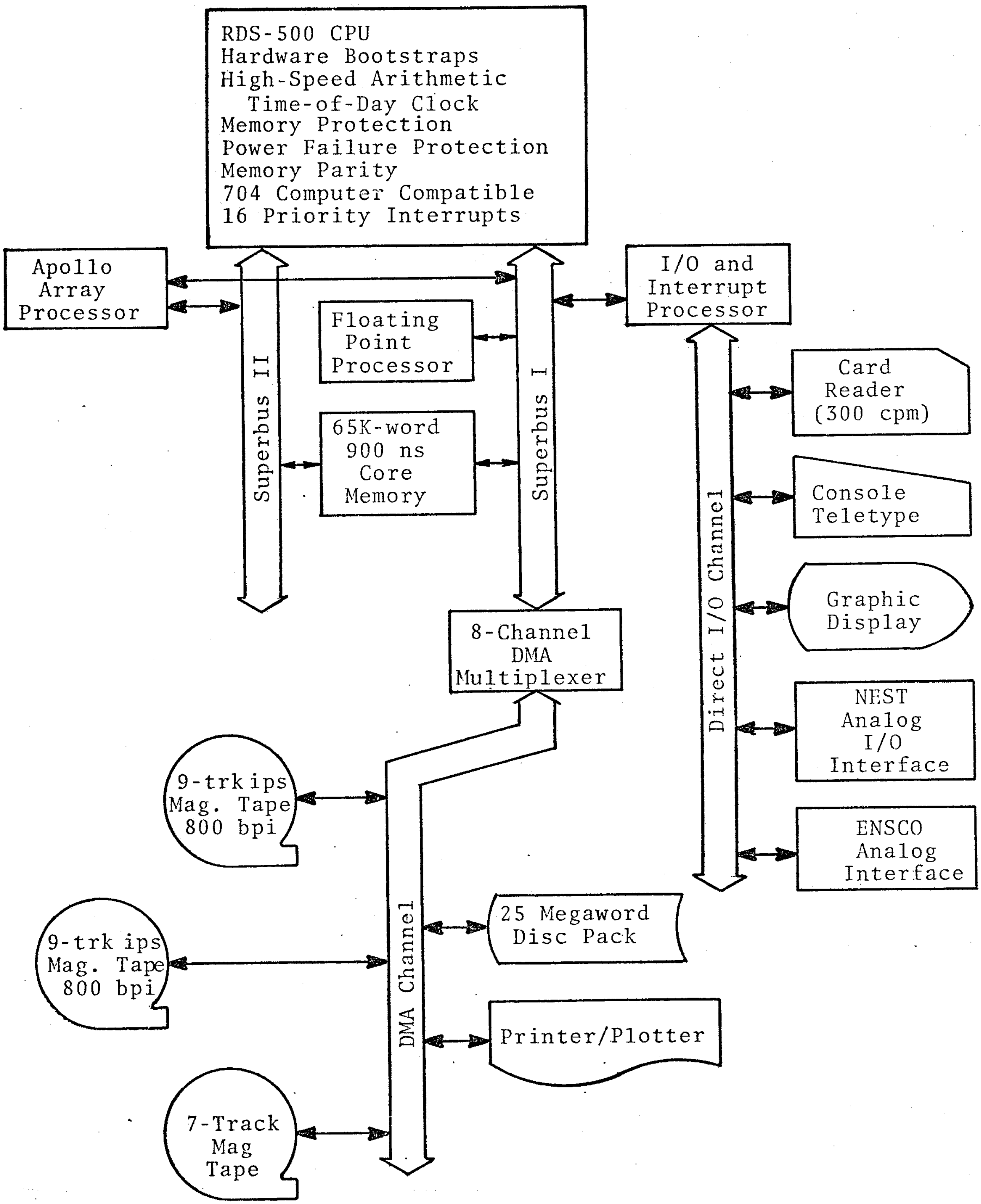


Figure 2. ENSCO RDS-500 System Configuration

2.0 DIGITIZING PROCEDURE

2.1 SOFTWARE

A procedure for generating a digital tape from the analog data has been developed, since the digital form of the data is more convenient for many applications and is essential for histogram analysis.

In the analog form, the voice channel is used to record information on existing conditions of the tests. To prevent the loss of this information in developing the data, a status bit was added to the digitizing data. The status bit is set by pressing a message unit button during the data collection process in response to the presence of information on the voice channel of the tapes. The information from the voice channel is then written on a test log sheet and identified with appropriate message sequence numbers. In this way, the digital records were correlated with the test log.

Each data record of the digital tape contains 128x7 words. There are 128 sets of data (called scans) per record. Each scan contains seven words. The first word is the status record, while the second through seventh words represent data from the channels. Each data record is one 16-bit word. The format of the status bit is

0111 1111 1111 normal status (no message)
1111 1111 1111 message indicator button pressed

Each data record word is left justified, with bits 0 through 11 containing digitized data. Bits 12 through 15 are not used. The end of each file is indicated by an end-of-file number.

The layout of the digital tape is shown in Figure 3. Within a given tape, a file has the format described in Figure 4. The file header contains 39 words (16 bits per word) as shown in Figure 5. The format of each scan is shown in Figure 6.

The digitized data represent an analog signal which can vary from -10 volts to +10 volts. Since the digitized data are represented by 12 bits, the number of discrete states is 2^{12} = 4,096. Each bin therefore corresponds to a voltage range of approximately 5 millivolts.

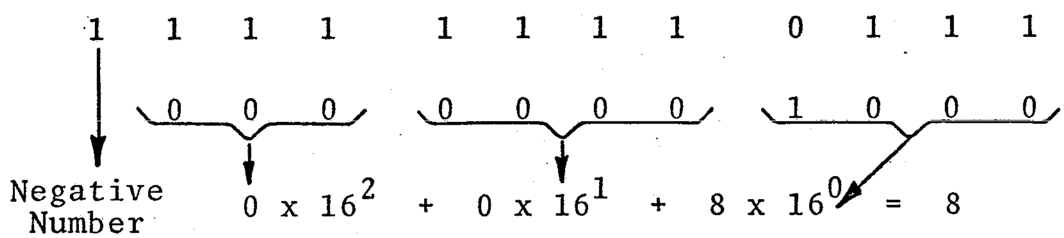
In decoding the digitized data, there are several rules to be followed. If the first bit is zero, then the voltage is positive, and the magnitude is given by the decimal equivalent of the remaining bits divided by 2,048 and multiplied by 10. For example:

0   1 1 1   1 1 1 1   1 1 0 1

Positive Number $7 \times 16^2 + 15 \times 16^1 + 13 \times 16^0 = 2{,}045$

$$\text{Value} = \frac{2{,}045}{2{,}048} \times 10 = 9.985 \text{ volts}$$

If the first bit is set, then the voltage is negative, and the magnitude is given by the following sequence. First, take the complement of the remaining bits, calculate its decimal equivalent, and add one. Multiple by 10 and divide by 2,048. For example:



$$\text{Value} = \frac{(8 + 1)}{2{,}048} \times 10 = 0.0439 \text{ volt}$$

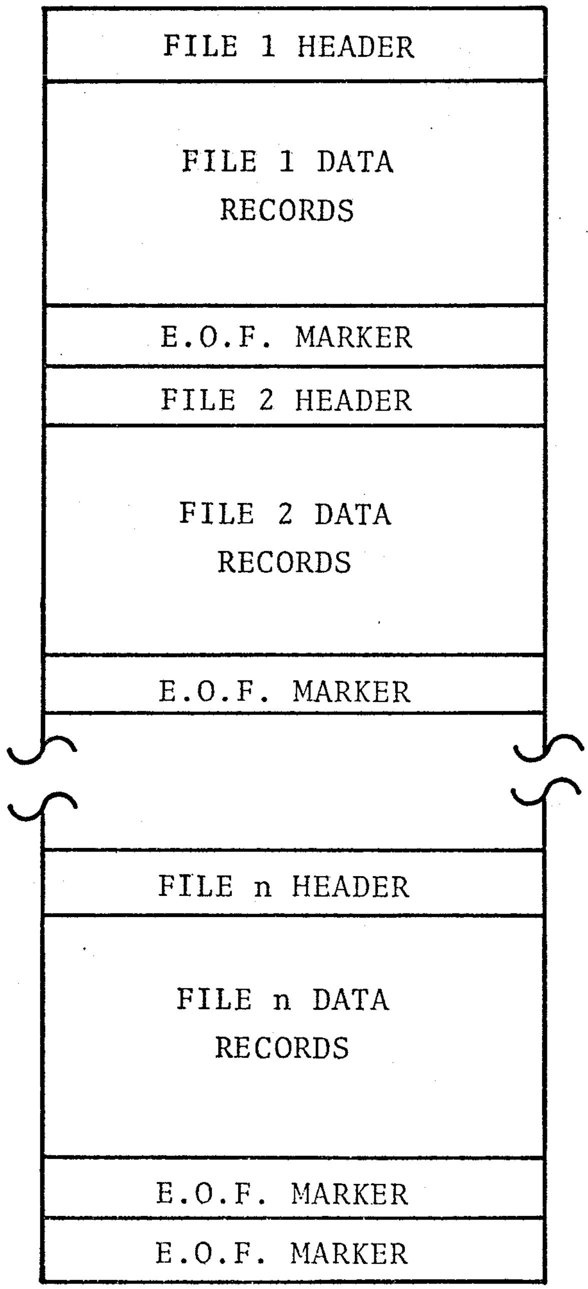


Figure 3. Layout of Tape

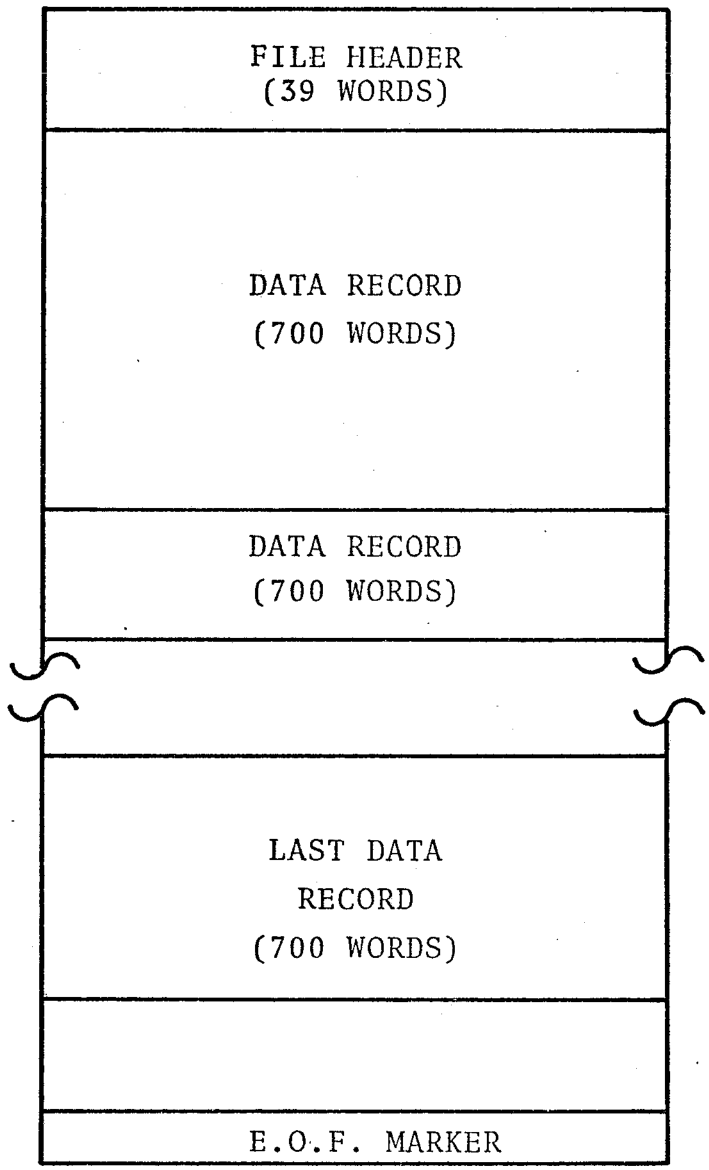
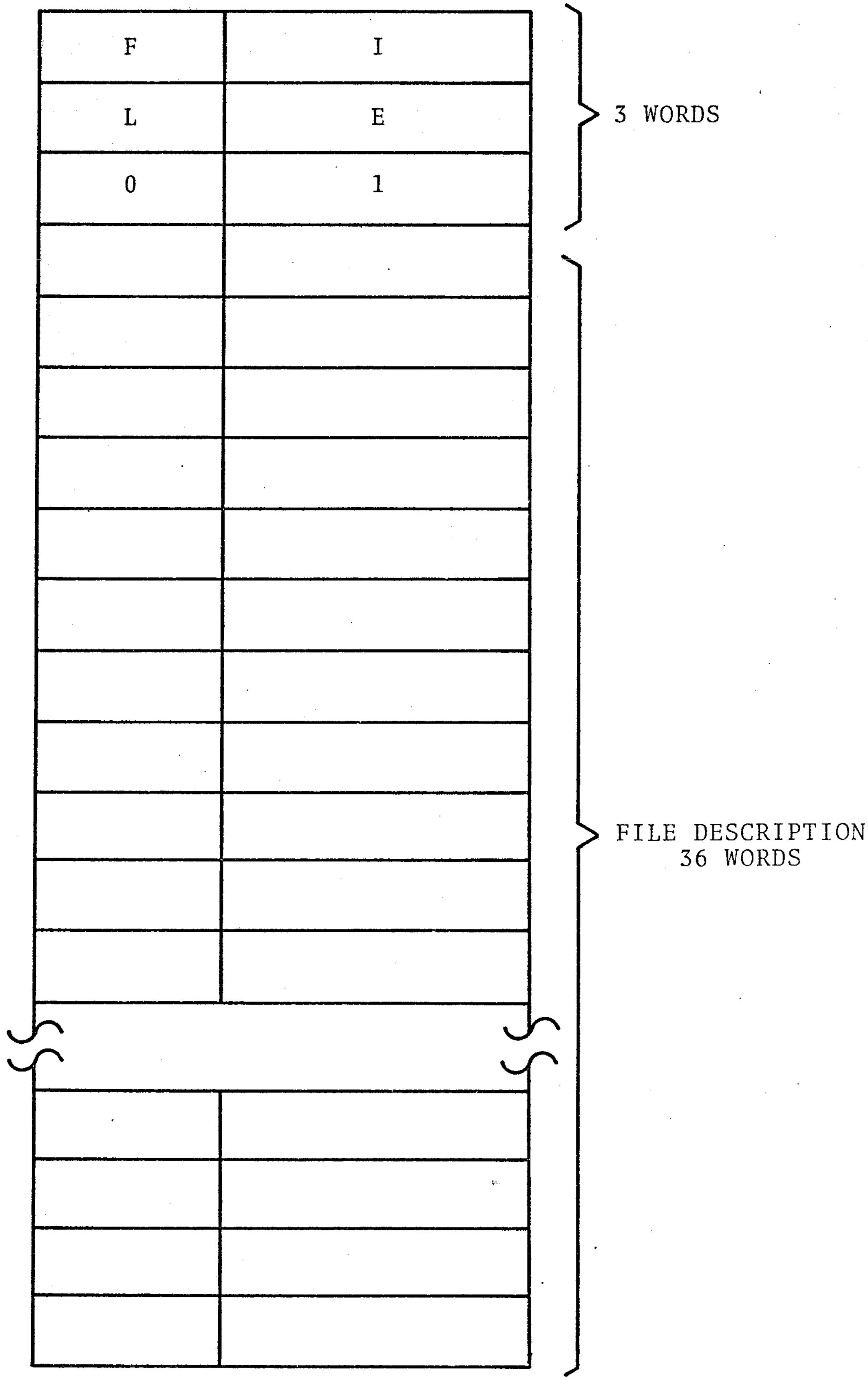
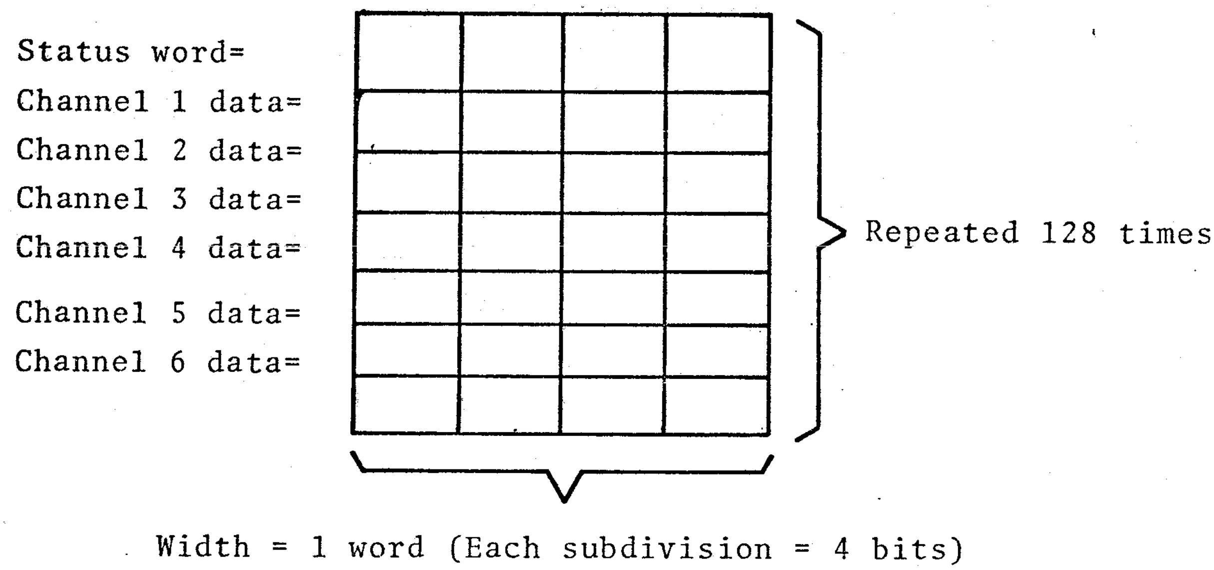


Figure 4. Layout of One File on Tape



WIDTH = 1 WORD (EACH SUBDIVISION = 8 BITS)

Figure 5. Layout of File Header Record



Status word:

(a) '7FFF' means measage indicator not depressed
(b) 'FFFF' means message indicator was depressed

Channel (n) data is left justified (i.e., 'FFFm', where the value of m is not used and should be shifted out before processing data).

Channel	Signal	Scale Factor
1	Roll	10 volts = 5 rad/sec^2
2	Pitch	10 volts = 1 rad/sec^2
3	Yaw	10 volts = 1 rad/sec^2
4	Vertical	10 volts = 1 G
5	Longitudinal	10 volts = 1 G
6	Lateral	10 volts = 1 G

Figure 6. Layout of File Data Record

2.2 PROCEDURE

For data reduction, the analog data are digitized using a 128-Hz digitizing rate. A 4-pole filter is used in reducing the data.

The following is a step-by-step description of the procedure for digitizing ride quality vibration (analog) data:

1. Set up the tape recorder, making sure that the correct reproduce cards are inserted. Connect the data cable from the tape recorder to the RQ interface panel. Check the switchable reproduce knob on the analog recorder. It should always be turned to one (1) when digitizing.

2. Connect the 6 BNC cables from the RQ interface to the filter panel. Roll must always be Channel 1. Standard channels are: 2-pitch, 3-yaw, 4-longitudinal, 5-vertical, 6-lateral. Check electrical power to the filter box. This power should always be on. Check rear cable from filter box to RQ interface. External switch should be up.

   Hardware filters should be checked for correct settings as specified by the user. Red filters should not be used for RQ processing. The filters used are Model "2" and are set as follows:

Bits	Frequency (Hz)	Bits	Frequency (Hz)
11	400	5	10
10	200	4	8
9	100	3	4
8	80	2	2
7	40	1	1
6	20		

   The procedure for setting each filter is as follows for a 25 Hz filter setting: Determine which bits are to be set (in this case, 6, 3, and 1). Reverse the filter and note the bit settings (the obverse numbers are not always correct). Each bit corresponds to four switches, two on each side. Therefore, when counting bits, count each two switches as one bit. Turn on the appropriate switches. Repeat this procedure for all six channels.

3. Inside the filter box are gain controls for each of the channels. The first two boards (left to right) correspond to the first six channels. For a gain of 1, this setting should be "2" (setting "1" for variable gain; "3" for gain of 5; "4" for gain of 10). Close the filter box. Turn the switches to filter setting.

4. Thread the tape through the device, turn the RQ interface on, switch the tape speed correlation to "in", and turn the volume up. By using both the message units and voice annotation, determine the desired section of data. (NOTE: Do not turn volume to maximum, since noise will be generated onto the data tape.)

5. To fully check the digitizing results, the following options can be selected:

   a. Check sampling frequency in intervalometer (after the digitizing program has loaded, start execution at location x '0801'). The intervalometer will have been set to the sampling interval when the TTY requests header information from the operator. Place oscilloscope probe on I.C. A-20, Pin 6, located on the intervalometer circuit board. The indicated pulse separation (negative pulses) will be the correct interval (in time).

   b. Check message unit (enter in computer the following at location zero):

Read	DIN 0,1	Loc 0000	Contents 0201
	JMP read	Loc 0001	Contents 1000

   Place computer in single-step mode and execute read status, jump sequence. The accumulator should contain $7FFF_{16}$. When the message button is pushed, the accumulator should contain $FFFF_{16}$ for one read and return to $7FFF_{16}$ upon reading the status again.

   c. Monitor the analog recorder output. Use the oscilloscope and monitor the voltage output of the analog recorder at the output terminals located on the front panel of the analog recorder, and at the analog-to-digital converter input terminals located in the bottom of the end computer rack. Note any offsets or saturations in voltage amplitudes.

d. Monitor the digital-to-analog converter output. Load and begin the execution of the digital conversion program using a scratch tape. When the program begins writing on the tape, monitor the output of the digital-to-analog converter using the oscilloscope. Check the data on as many channels as are being digitized. Note any offsets or saturations in output amplitudes.

6. To load the program, enter the following from the keyboard:

:QUB,DIGITIZE/TIP,,X,Y,Z,1

where:

X = number of channels = 6

Y = digitizing rate = 128-Hz

Z = number of scans/redord = 128 or 256

:XX

After the program is loaded, the program will sit at location X '0850'. At this point, do the following:

Halt the CPU

Reset the CPU

Enter X '0801' in PCR

Press run

Hang write-enable data tape on unit 0

Toggle sense switch 0

The Tektronix will print the program title and ask the operator to enter the tape header information. Up to 70 characters may be entered through the Tektronix in the following manner:

line feed, 5X, date, ID, sample rate, etc. return

7. There are three sense switches used by the digitizing routine, as follows:

Sense Switch	Position	Operation
0	Down	Program will not digitize
	Up	Digitizing will be initiated
1	Down	No operation
	Up	EOF will be written on tape
2	Down	No operation
	Up	2 EOF's will be written and tape will rewind

8. To operate, do the following:

   a. Start tape recorder.

   b. Place sense switch "0" up to start.

   c. Place sense switch "0" down to stop.

   d. Toggle switch "1".

   e. Enter new header.

   f. Repeat steps b, c, d and e as often as needed.

   g. On the last file, toggle switch "2" to end process.

3.0 SOFTWARE ANALYSIS

3.1 VISUAL EXAMINATION

Before processing can be done on collected data, the time history plots of that data must be visually examined. Speed, location, and other reference information from the voice channel should be annotated on the charts. The PRQ reconstruction unit and a strip chart recorder are required to display the raw data.

In addition, software programs exist to plot time series data from the digital data. Based on this presentation of the plotted data, segments can be selected for further data reduction.

During the visual examination of the plots, bad data should be determined and recorded. This will include bad spots on the tape, locations where the package may have been touched, and times when the system was temporarily turned off.

3.2 TIME DOMAIN

In processing the ride quality data, the date must be analyzed in the time domain.

After digitization, the data can be processed to achieve

- Peak values.
- Histograms.
- Probability density functions.
- Cumulative distribution functions.
- Standard deviations.

Figure 7 is a block diagram of the data reduction process.

A digital high-pass filter (shown in Figure 7) removes any bias in the accelerometer data. Appendix C contains a description of the algorithm for implementing the block diagram. A bias in the level of the accelerometer output can arise if, in the placement of the accelerometer package, the vertical axis (with a 1-g biased accelerometer) is not exactly aligned with the direction of gravity. In practice, the package will never be exactly in position, and all of the linear accelerometer signals will have some DC bias.

In addition, an electronically induced bias from the frequency modulating and demodulating processes can exist. If the DC bias is not removed, the histograms, cumulative distribution functions, and density functions will be offset from the zero level of acceleration.

The histograms for the ride quality data analysis were developed by sorting the digitized data into 200 bins. With the range of the input data from the PRQ corresponding to +10 volts to -10 volts, each bin has a range of 0.1 volt. The bins can be numbered in order, with bin 1 covering the range -9.9 to -9.8 volts, and bin 200 the range +9.9 to +10.0 volts. A vector b_i with 200 elements can be used to represent the results of the sorting process. The value of the ith element of the vector represents the number of times the processed data had a value which fell within the ith bin.

Peak values (i.e., the highest and lowest values of acceleration) recorded during a given segment of the test can be

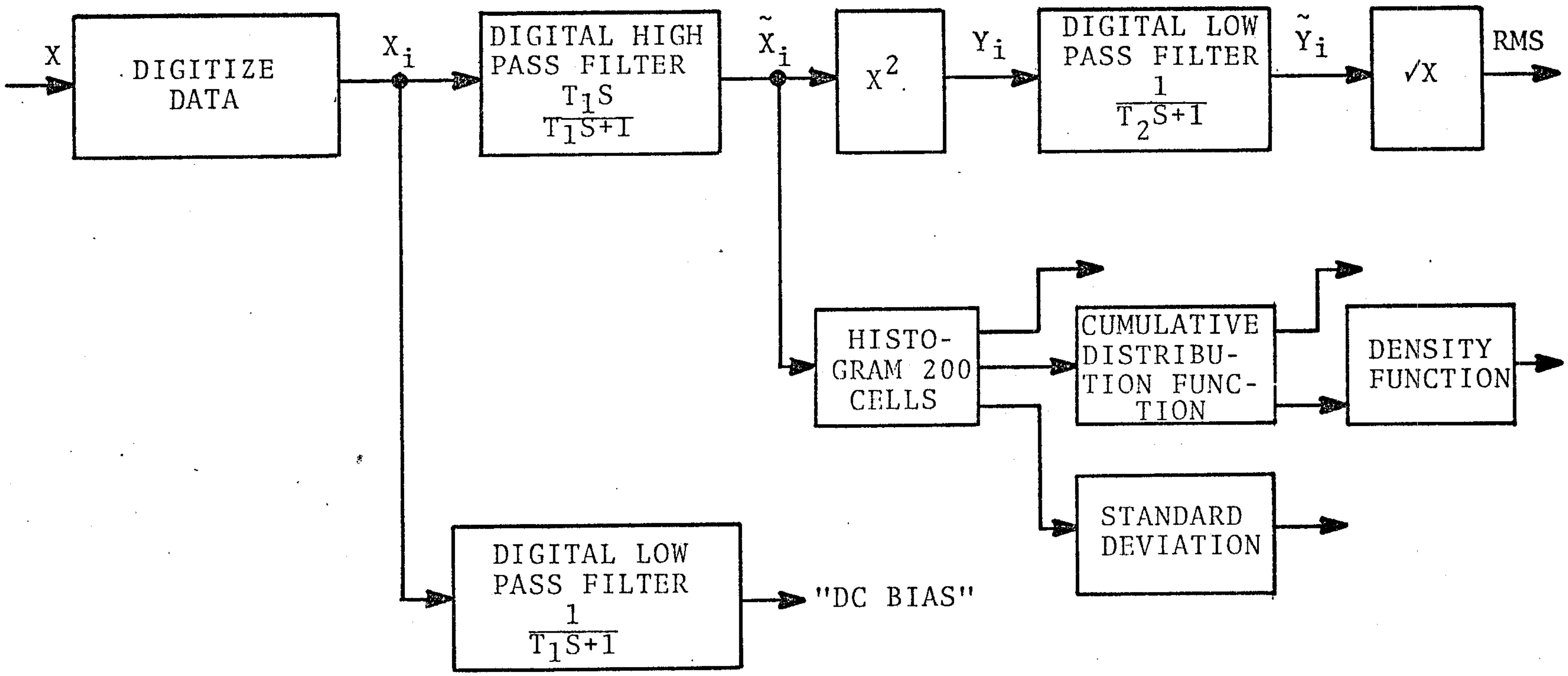


Figure 7. Block Diagram for Data Reduction (One Channel)

found from vector b_i. An alternative method is to present the data inanalog form. Two forms of presentation of data are described below. One is an estimate of the probability density function; the other, an estimate of the cumulative probability function.

The cumulative probability function gives the probability that the value of a function will be less than some value X; i.e.,

$$P(x<X) = Y(X)$$

This function can be estimated from the vector b_i by the expression

$$Y_j = \frac{\sum_{i=1}^{j} b_i}{M}$$

where M is the total number of samples.

The probability density function is the derivative of the cumulative probability function. The probability density function is given by

$$Z_j = \left(\frac{b_i}{M}\right) \left(\frac{N}{2SF}\right)$$

where N is the number of bins, M is the total number of samples, and SF is the scale factor (acceleration units per 10 volts).

The abscissa for plotting Y_j and Z_j is derived from the scale factor for a channel by the expression

$$X_j = -SF + 2 \left(\frac{SF}{N}\right) j$$

where j takes on values from 0 to N (N equals the number of bins).

The mean value and the standard deviation of the distribution estimated from vector b_i can be calculated along with the probability density function and cumulative probability function.

The mean value can be estimated by

$$\mu = \sum_{i=1}^{N} b_i \frac{(X_i + X_{i-1})}{2M}$$

where b_i = occurrence vector.

The standard deviation can be estimated by taking the positive square root σ of variance σ^2, as given by

$$\sigma^2 = \int_{-\infty}^{+\infty} (X - \mu)^2 P(X)\, dX$$

$$= \int_{-\infty}^{+\infty} X^2\, P(X)\, dX - \mu^2$$

$$= B - \mu^2$$

where P(X) is the probability of X.

The limits on the integral can be changed from $-\infty$ to $+\infty$ in value, corresponding to -10 volts to +10 volts.

$$B = \int_a^b X^2 f(X)\, dX$$

where the interval a to b is made up of 200 bins.

The contribution of any bin will depend on the distribution of raw data within the bin. For the purpose of this analysis, assume that the raw data are equally distributed within a bin. The contribution of the Nth bin is represented by

$$B^N = \int_{X_{N-1}}^{X_N} X^2 P(X)\, dX$$

$$= \int_{X_{N-1}}^{X_N} X^2 \frac{b_i}{M\left(X_N - X_{N-1}\right)}\, dX$$

$$= \frac{b_i}{3M} \frac{\left(X_N\right)^3 - \left(X_{N-1}\right)^3}{X_N - X_{N-1}}$$

$$= \frac{b_i}{3M} \left(X_N^2 + X_N X_{N-1} + X_{N-1}^2\right)$$

Since $X_N = X_{N-1} + \Delta$, the expression can be rewritten as

$$B^N = \frac{b_o}{M} \quad X_{N-1}^2 + X_{N-1}\,\Delta + \frac{\Delta^2}{3}$$

where $\Delta = \frac{2\ SF}{N}$.

The variance can be written as

$$\sigma^2 = \left[\sum_{i=1}^{N} \frac{b_i}{M} \left(X_{i-1}^2 + X_{i-1}\,\Delta + \frac{\Delta^2}{3}\right)\right] - \mu^2$$

$$= B - \mu^2$$

The standard deviation is given by σ.

Note that the mean value μ should be zero since the data have been high pass filtered, but a value is allowed in this analysis for completeness.

The digitized acceleration data can be used to generate an level of acceleration versus time. The data are effectively condensed in this form so that the averaging effect of the process compensates for the rapidly varying characteristics of the signal. The results of a given segment of the run can then be displayed on a reduced time axis. For example, the raw data with frequency components up to 30 Hz require that 1 second of data corresponds to approximately 1 inch of display. With the high-frequency characteristics of the signal removed, 1 inch can be used to display about 10 seconds of data. The characteristics of the digital low-pass filter shown in the top row of Figure 7 determine the exact smoothing time of the rms. The time constant τ_2 is related to the corner of the low-pass filter by

$$\tau_2 = \frac{1}{2\pi f_c}$$

which for a 0.5-second value of τ_2 implies a corner frequency of about 0.3 Hz.

3.3 FREQUENCY DOMAIN

Power spectral density (PSD) estimates are generated in the ride quality data reduction program. The frequency spectrum (or PSD) of the acceleration is important in determining the quality of the ride. A human is particularly susceptible to vibration in the 1- to 8-Hz range. PSD levels in this range can normally be related to ride quality.

The PSD's are generated using a fast Fourier transform (FFT) technique and a stacking operation. The FFT is applied to each 4-second segment of data, and the resulting spectral estimation for each 4-second segment is averaged over the entire record. The plots of PSD's are for spectrum level versus frequency. The frequency axis is given in a linear form and the spectrum level in dB form. The reference level for the dB level is 1 g^2 (rms)/Hz. A more detailed description of the frequency domain processing is given in Appendix A.

In addition, ride quality results are given in terms of ISO and W_z criteria. The ISO criteria is given in Appendix A and the W_z method in Appendix E.

4.0 SOFTWARE PROGRAM

4.1 DESCRIPTION

A vehicle vibration software package has been developed for reducing the data collected with the ride quality instrumentation. The input to this program consists of six channels of data per run and is setup in records containing 128 scans per second.

This program takes acceleration data, performs both time and frequency domain processing, and outputs the results in a format that can easily be placed in a report.

4.2 INPUT

The following input parameters are required for operating the data reduction program:

Data Card No.	Parameter	Format
1	CDS (SUN for card reader)	I5
2	INTAPE (SUN for input tape)	I5
3	OUTAPE (SUN for rms output tape)	I5
4	PTR (SUN for printout)	I5
5	SCRFILE (SUN for Cepstrum, SF's, and common)	I5
6	SCRTAPE (SUN for Cepstrum output)	I5
7	RECSCANS (Number of scans/ record)	I5
8	JUST (left or right justified)	I5
9	SCANINCR (scan increment)	I5
10	LABLCH (channel headings or channel units)	3GA2
11	CHANS (channel numbers)	9I5
	ISOCHS (ISO channel numbers)	
12	VRANGE (voltage range)	8F10.1
	SF (volts/engineering units)	
13	A1, B1, C1, D1 (filter constants)	I5
14	AA (PSD printout option)	I5
15	ACFOPT (ACF option)	I5
16	REWIND (rewind option)	I5
17	BFILE (beginning file)	I5
18	BREC (beginning record)	I5
19	EREC (ending record)	I5
20	ICARD (supplemental heading)	40A2

Figure 8 is a list of the control cards.

```
¤NJ,L
¤IO,3,24
¤CO, TIME ON, NEW RN,1116,414.5,      ROBEY
¤OT
¤NJ
¤IO,3,24
¤QUE,GLDCHG
¤CO,ASSIGN 3 TO PTR, 4 TO L1 TEMP RMS AND RMS SF?S + CARDS, 5 TO APOLLO,
¤CO, 6 TO INPUT TAPE ON 9-TRK 0, 7 TO FINAL RMS ON 9-TRK 1, 8 TO L4
¤CO, CALCOMP OUTPUT, 9 TO 7-TRK(1-0) CEPSTRUM DATA AND PLOTP2 OUTPUT,
¤CO, 10 TO L3 CEPSTRUM SF?S + COMMON (LATER TO L0 FOR CEPSTRUM SCRATCH)
¤IO,3,24,4,L2,5,30,6,16,7,17,8,L4,9,18,10,L3
¤RW,4,6,7,8,9,10
¤QUB,VIBES/TIP
     2          CDS          SUN FOR CARD READER
     6          INTAPE       SUN FOR INPUT TAPE ON 9-TRK UNIT 0
     7          OUTAPE       SUN FOR RMS OUTPUT TAPE ON 9-TRK UNIT 1
     3          PTR          SUN FOR PRINTOUT
    10          SCRFILE      SUN FOR CEPSTRUM  SF?S AND COMMON DUMP
     9          SCRTAPE      SUN FOR CEPSTRUM OUTPUT TAPE ON 7-TRK (1-0)
   128          RECSCANS     SCANS PER RECORD
-    1          DATA IS LEFT JUSTIFIED
     1          SCANINCR (1 EQUIVALENT OF 2 IN OLD PACKAGE)
     ROLL       PITCH         YAW         LONG        VERT        LAT
RAD/SEC/SEC RAD/SEC/SEC RAD/SEC/SEC       G?S         G?S         G?S
     1    2    3    4    6    5    4    6    5    CHANS AND ISHOCHS
-10.        10.        .5        .1        .1        .1        .1        .1
.984496124.007751938.984496124.007751938
     1          PSD PRINTOUT OPTION IS YES
                REWIND OPTION IS NO

     1
    10
    69
   PIACV    AT IDLE  RECORDS 10-70
¤CO,REWIND ALL UNITS FINISHED WITH AND COMMON DUMP FOR NEXT PROGRAM READ
¤RW,4,6,7,9,10
¤QUB,VIBES2/TIR
    10           SUN FOR CEPSTRUM SF?S AND COMMON DUMP-LOAD TO VIBES2
¤CO, REWIND UNITS FINISHED WITH AND CEPSTRUM SF?S ANC COMMON
¤RW,4,10
¤CO, ASSIGN 7 TO CEPSTRUM SF?S ON L3, 9 TO CEPSTRUM DATA ON 7-TRK(1-0),
¤CO, AND 10 TO DISK L0 FOR SCRATCH
¤IO,7,L3,9,18,10,L0
¤QUB,VIBCPTRM/TIR
   128.         10    4   30 12 S
     7           SUN FOR SF?S, CHANNEL LABELS ETC
¤CO, REWIND UNITS FINISHED WITH AND FREE UP 9 FOR PLOTP2
¤RW,7,9,10
¤CO, ASSIGN UNITS FOR PLOTP2
¤IO,8,L4,9,L5
¤CO, REWIND UNITS FOR PLOTP2
¤RW,8,9
¤QUB,PLOTP2
¤IO,3,24
¤QUB,PLOTP3
¤CO, ASSIGN 2 TO L1 FOR CARD INPUT, 8 TO 9-TRK 1 FOR RMS INPUT TO RQPLOT
¤IO,2,L2,8,17
¤QUB,RQPLOT/TIP
¤CO, RETURN 2 TO CARD READER
¤IO,2,20
¤NJ,L
¤IO,3,24
```

Figure 8. List of Control Cards

4.3 OUTPUT

The output of this data reduction package consists of 22 pages of summaries, graphic estimates, and plots. The output includes:

- Probability density estimates and plots.
- Distribution function estimates and plots.
- One-third octave band rms levels.
- The ISO ride quality exposure time for the reduced confort criteria.
- Power spectral density levels and plots.
- Cepstrum plots for PSD levels.
- RMS levels.

The format of the output is given in Appendix A and is explained below.

Pages 1 and 2 describe the probability density estimate. The probability density is a function of the number of data location bins, the total number of samples, and the channel scale factor. Each page has 12 columns, two columns for each channel. The first column of each channel gives a specified engineering setting which corresponds to an acceleration level. The second column of each channel gives the value of the probability density function which, when multiplied by the width of the bin, provides the probability associated with each bin. The heading for each of these six channels is an alphanumeric input, and it can include both the channel number and a short description of what data were recorded on the channel. The heading shown at the top of each page is an alphanumeric input applicable to points of interest (such as type of test, date, location of test, number of scans, and record numbers). The units are g's for linear acceleration channels and radians per second/per second for reotational acceleration channels. At the end of Page 2, the standard deviation of the six channels is given. The standard deviation is given in engineering units (such as g's and radians per second/per second), based on the scale factor for each channel. The scale factor relates the voltage level to the measured engineering units (g's per volt). The data are digitized at a rate of 128 Hz, and 1 second of data is recorded per record. Thus, the number of scans (data points) corresponds to the number of records multiplied by the digitizing rate. This value is also shown at the top of Page 1.

Pages 3 and 4 contain the distribution function estimate. Again, two columns are given for each channel, with the first column corresponding to a voltage setting and the second column to an estimate of the distribution function.

For ride quality data analysis, one-third octave band filtering provides a correspondence to the International Standards Organization (ISO) standards for determining the quality of the ride. Pages 5 and 6 of the standard ride quality data analysis package give the rms acceleration for the filtered data. For center frequencies ranging from 1 Hz to 31.5 Hz, results are given for longitudinal, lateral, vertical, roll, pitch, and yaw accelerations. For each band, the mean is reported (expected value - EV) along with the mean plus or minus one standard deviation (UB - upper band, LB - lower band).

Power spectral densities are presented on Pages 15 through 20. The PSD's are developed using a stacking operation and the fast Fourier transform, which operates on blocks of data containing 512 points. The x-axis is a frequency axis which varies from 0 to 40 Hz. The y-axis prints out the power spectral density (PSD) level in dB relative to 1 g (rms) squared per hertz rms. The plots are titled as to which channel is represented and what phase of testing is represented. In addition, the rms level, which is computed by summing up the PSD levels, is given.

On the next pages, a time history of the rms acceleration level is given for each of the channels. Page 21 gives a description of the channels and the scale factors used in the plots. Page 22 gives the rms plots, which are useful in determining relative amplitudes and an overall profile of the parameters being recorded.

4.4 SUBROUTINES

The software is divided into various subroutines and are flow charted in Appendix G.

APPENDIX A

COMPUTER IMPLEMENTATION OF ISO STANDARD 2531 FOR PROCESSING RIDE VIBRATION DATA

1.0 INTRODUCTION

Human response to mechanical vibration is complicated and not well understood. Although human response to vibration has been investigated for many years, no universally accepted method of evaluating ride quality from mechanical vibration exists. However, it is generally accepted that man's tolerance to vibration is frequency dependent. Many investigators of ride quality have presented their results in terms of acceleration amplitude-frequency curves.

One method of evaluating the ride quality of a vehicle from acceleration environmental data is to use the ISO standard entitled "Guide for the Evaluation of Human Response to Whole-Body Vibration," which presents three criteria for evaluating ride quality:

- The preservation of working efficiency (fatigue-decreased proficiency boundary).
- The preservation of health or safety (exposure limit).
- The preservation of comfort (reduced-comfort boundary).

Based on each criterion, two sets of amplitude-frequency curves are defined. One curve is for longitudinal acceleration (foot-to-head direction), and the second is for transverse acceleration (back-to-front or side-to-side direction). For each amplitude-frequency curve, a set of boundaries is defined and denoted by exposure times. The tolerable acceleration level increases with decreasing exposure time. The acceleration limits for transverse acceleration as a function of frequency for various exposure times (for the fatigue-decreased proficiency criteria) are shown in Figure A1. Similar curves for the longitudinal direction are shown in Figure 2A.

For the set of curves associated with the exposure limit criteria, a factor of 2 (or 6 dB) times the values for the decreased proficiency criteria shown in the curves is introduced. Correspondingly, a factor of 0.315 (or -10 dB) is introduced to obtain the set of curves for the reduced-comform criteria.

These curves are defined for a sinusoidal acceleration signal. In practice, this form of acceleration is not likely to occur, and one-third octave band filtering is defined as the appropriate method for applying the standard to random (broadband) vibration signals.

The standard is defined over the frequency range from 1 Hz to approximately 90 Hz. A set of 20 one-third octave band filters is required to cover this frequency band. The one-third octave band filtering provides an rms acceleration level for each of the 20 filters. The standard is used to convert each rms acceleration level to exposure time. The minimum exposure time from the 20 bands is taken as the description of the ride. For instance, the reduced-comfort cirteria would be used to evaluate a passenger vehicle. The ISO standard provides a means of assigning a single number (say, 5 hours) to the ride, based on the acceleration environment. The exposure time is for a 24-hour period.

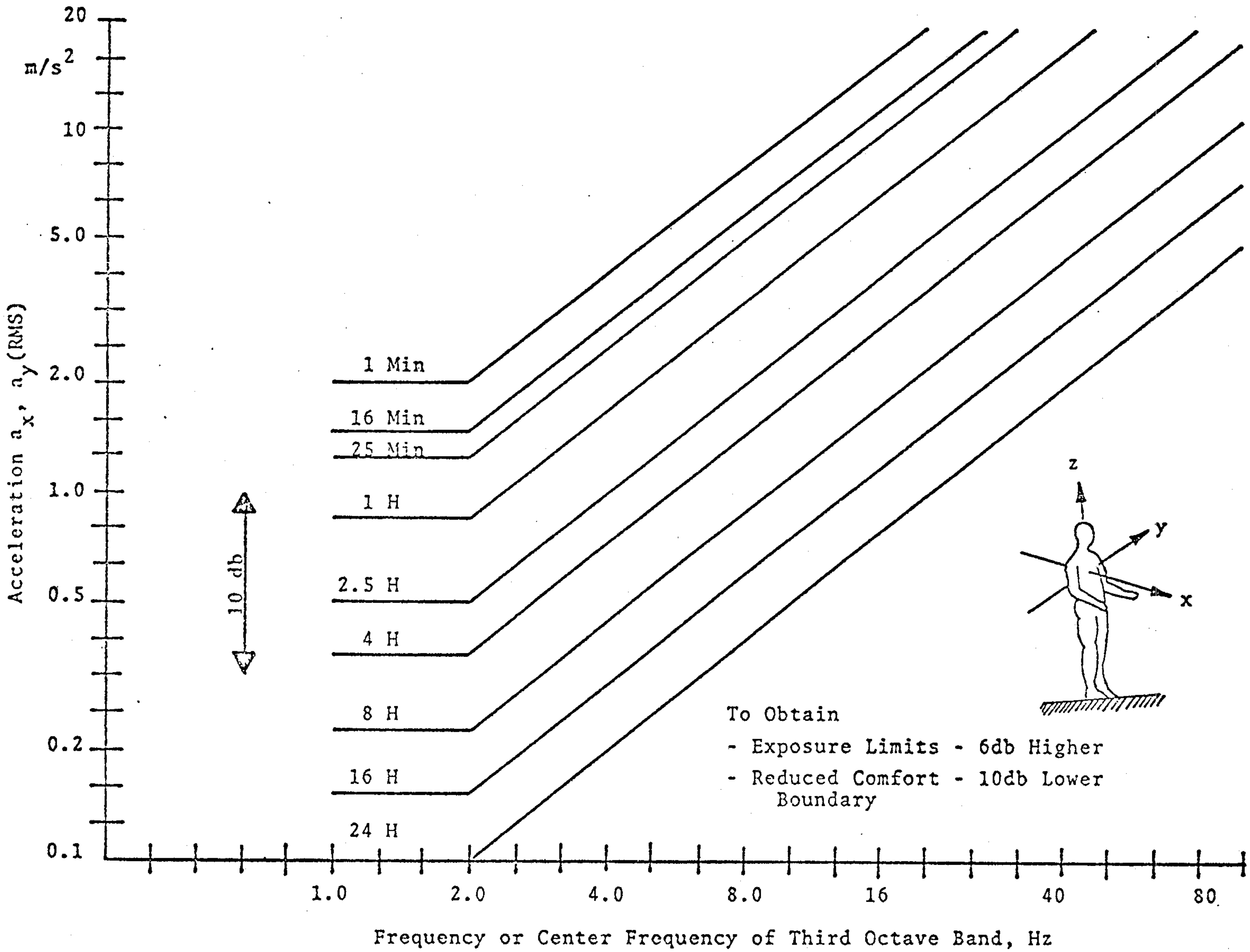


Figure A1. Transverse Acceleration as a Function of Frequency and Exposure Time (Fatigue-Decreased Proficiency Boundary)

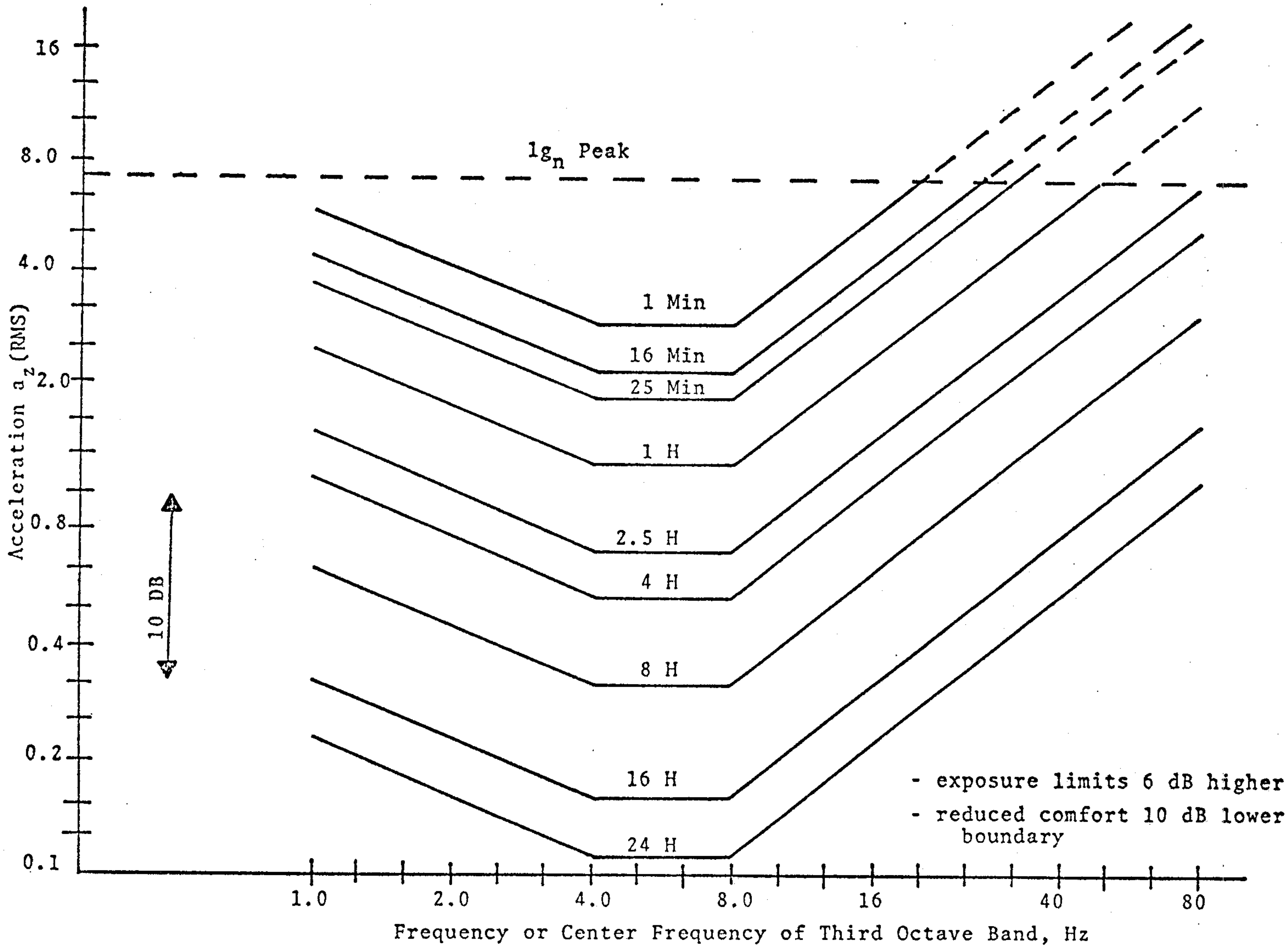


Figure 2A. Longitudinal Acceleration Limits as a Function of Frequency and Exposure Time (Fatigue-Decreased Proficiency Boundary)

2.0 TECHNICAL APPROACH

The objective of this effort was to apply the ISO standards to ride acceleration data using digital computer techniques. The following steps were taken to achieve this goal:

- Convert the time series data into outputs that represent the rms levels of each of the 20 ISO bands for each of the three directions--vertical, lateral, and longitudinal.
- Take each rms level and, depending on its orientation (vertical, lateral, or longitudinal), find the minimum appropriate exposure time as specified by the ISO standards.
- Tabulate the time limits for each band and prescribe confidence intervals for them. Search the time limits for the minimum time and list this information along with the offending frequency band(s) and direction(s) of vibration.

ENSCO's approach to implementing the ISO standards is described in the following paragraphs. A straightforward building block approach was used, as shown in Figure A3, following the three steps listed above.

2.1 FREQUENCY DIVISION OF DATA

The analog data are usually low pass filtered at 20 Hz to prevent aliasing* prior to being digitized at a sample rate of 128 values per second. This rate is chosen in anticipation of the method that is used to partition the data in the frequency domain--the fast Fourier transform (FFT). The FFT operates on

*Aliasing is a process by which high-frequency signals are sampled at an insufficient rate (less than two samples per cycle for periodic components) needed for reconstruction.

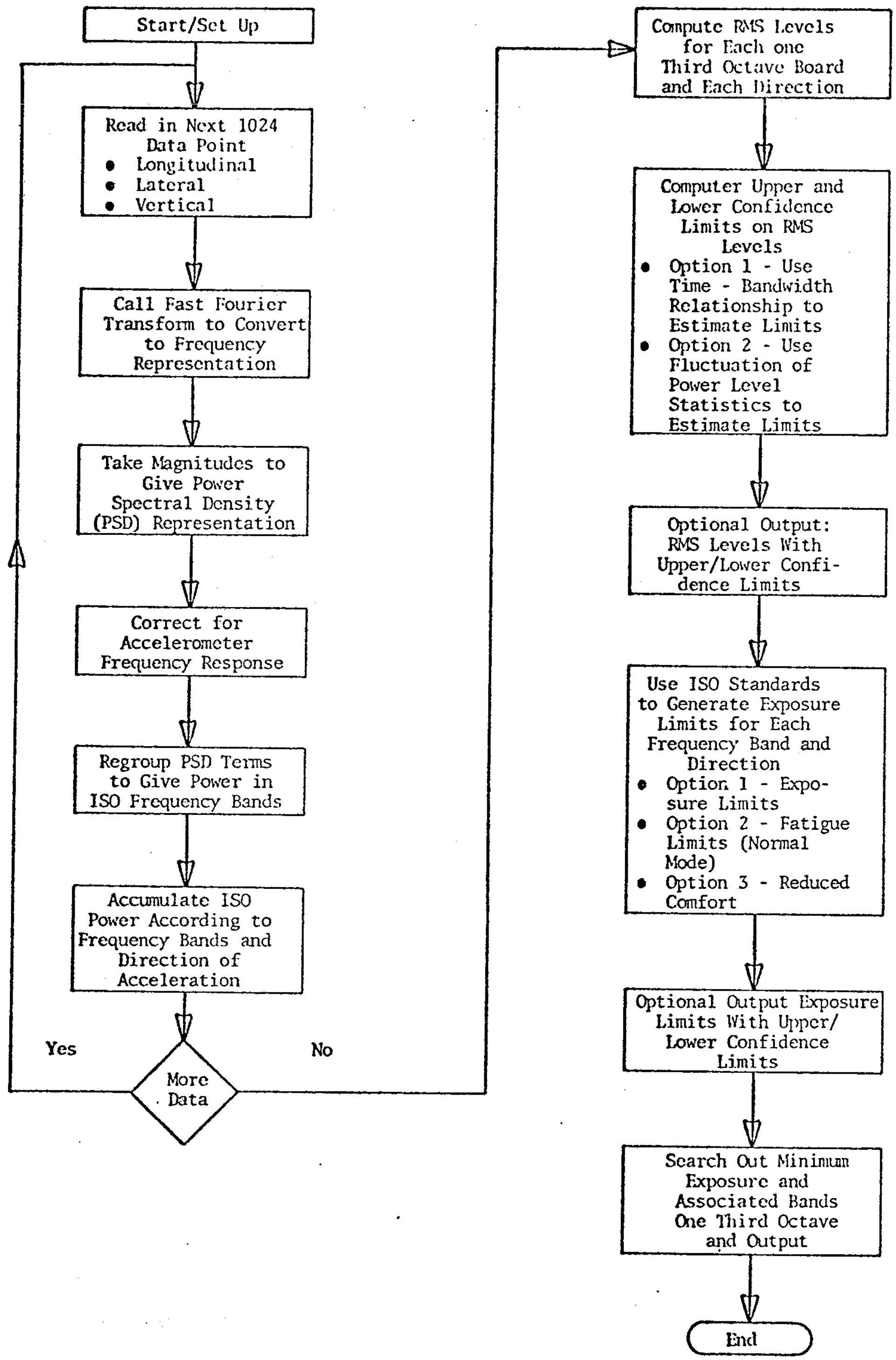


Figure A3. Conceptual Flow Chart

on blocks of data containing 2^N consecutive time samples. Here, N is an integer and, in this case, is 10(2^{10} = 1,024 samples). Thus, each block of data has a duration T of exactly 4 seconds.

The output of the FFT is a complex array of dimension 1,024. This array represents the frequency distribution for the input time series. Each complex element of the array resembles the output of a narrowband filter centered at frequency $(n-1)f_o$, and having a bandwidth of ($f_o = \frac{1}{T} = 0.25$ Hz). This is true for n = 2 through n = 512.

Complex array element n = 1 has a zero imaginary part, and its real part is the mean (DC) value of the signal. Complex array element n = 513 is the folding frequency for the sample interval chosen. Elements 514 through 1,024 contain the so-called negative frequency components and, for the real input process, contain no new information.

2.1.1 PARTITIONING PROCESS

The ISO standards are concerned with the vibrational energy in 20 frequency bands centered at one-third octave intervals. Each of these bands covers a one-third octave range. The salient characteristics of these frequency bands are given as follows:

- Center frequency: $\Psi_m = 10^{(m-1)/10}$, m = 1,2,3,...20
- Lower cutoff frequency: $\Psi_m^\ell = 10^{(m - 1.5)/10}$
- Upper cutoff frequency: $\Psi_m^u = 10^{(m - 0.5)/10}$
- Bandwidth: $\delta_m = \Psi_m^u - \Psi_m^\ell = 2.32\Psi_m$

These characteristics are summarized in Table A1 for each of the 20 ISO bands.

Table A1. ISO Center Frequency, Cutoff Frequencies, and Bandwidths (All Frequencies in Hz)

ISO Band	Center Frequency (ψ_m)	Lower Frequency Cutoff (ψ_m^ℓ)	Upper Frequency Cutoff (ψ_m^u)	Bandwidth (δ_m)
1	1.00	0.89	1.12	0.232
2	1.26	1.12	1.41	0.292
3	1.59	1.41	1.78	0.368
4	2.00	1.78	2.24	0.463
5	2.51	2.24	2.82	0.583
6	3.16	2.82	3.55	0.734
7	3.98	3.55	4.46	0.924
8	5.01	4.46	5.62	1.16
9	6.30	5.62	7.07	1.46
10	7.95	7.07	8.90	1.84
11	10.0	8.90	11.2	2.32
12	12.6	11.2	14.1	2.92
13	15.9	14.1	17.8	3.68
14	20.0	17.8	22.4	4.63
15	25.1	22.0	28.2	5.83
16	31.6	28.2	35.5	7.34
16	39.8	35.5	44.6	9.24
16	50.1	44.6	56.2	11.6
17	63.0	56.2	70.7	14.6
20	79.5	70.7	89.0	18.4

To transform the FFT output to data usable in the ISO standards requires two steps:

- Convert the complex array output into an energy-related variable.
- Partition these data into the ISO bands.

The first step is illustrated in Figure A4. Each of the useful array elements ($n = 5$ through $n = 358$) is multiplied by its complex conjugate. The unused array elements are discarded, since they lie outside the frequency range of interest or they contain redundant information. The resultant is multiplied by a constant array C that compensates for the frequency response of the accelerometers. This quantity is then multiplied by another fixed constant ($2/1,024^2$) that converts the result into a mean square acceleration level. The result is placed in an array called W.

The second step is more difficult and is illustrated in Figure A5. This process is called partitioning, and it takes energy that is distributed in the linearly uniform frequency bins and redistributes the energy into ISO bins that are exponentially spaced. The procedure involves straight summing, except where some of the bins straddle the ISO band limits. Then the energy is divided appropriately between the two adjacent ISO bands.

2.1.2 FREQUENCY RESPONSE CORRECTION

In general, the accelerometers that monitor the ride environment do not have a flat frequency response over the entire ISO range. However, these accelerometers are usually of the servo variety. Their frequency response characteristics can be described by two parameters: the 90° phase shift frequency f_o, and the damping factor b.

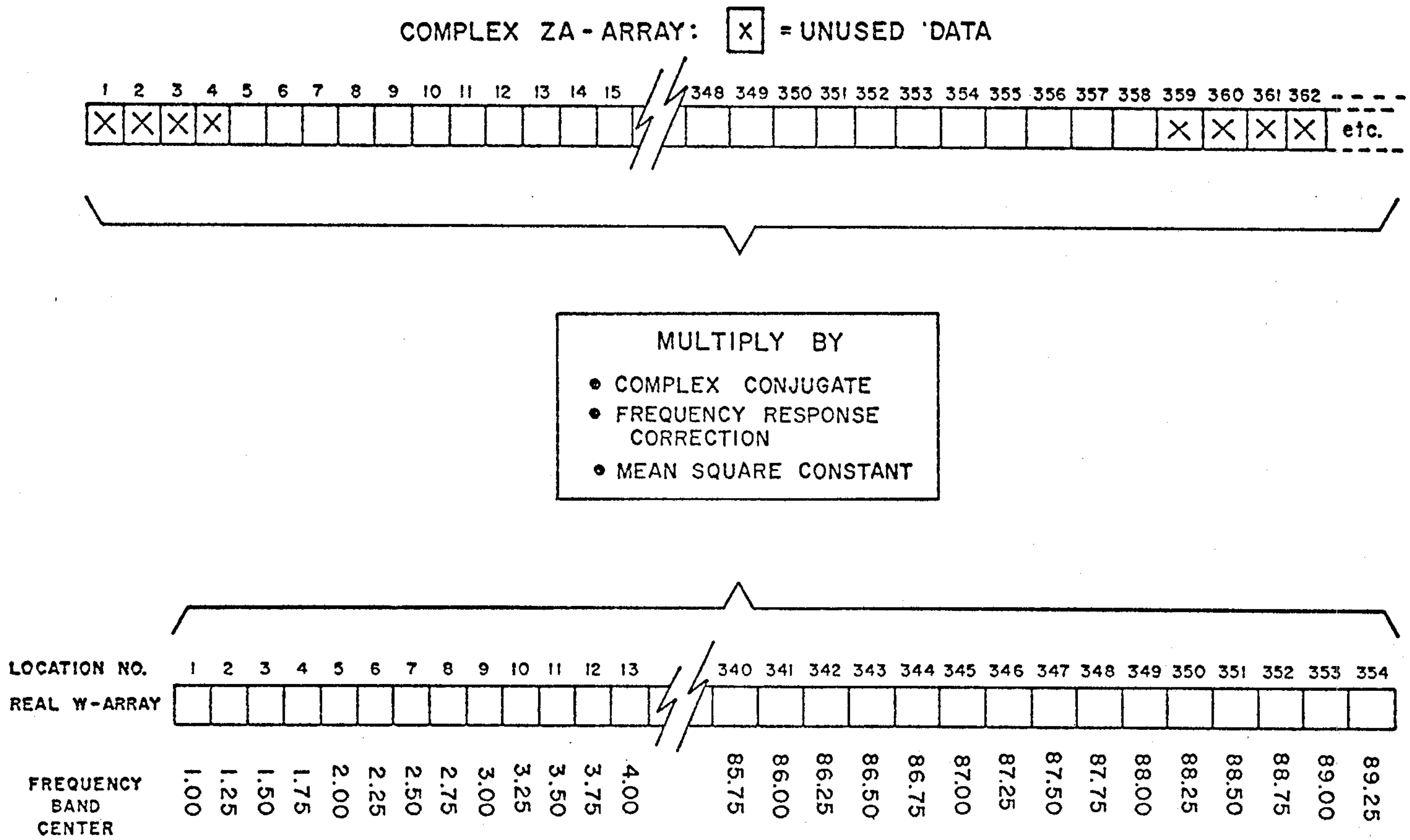


Figure A4. Procedure for Obtaining Corrected Energy-Related Variables from FFT Output

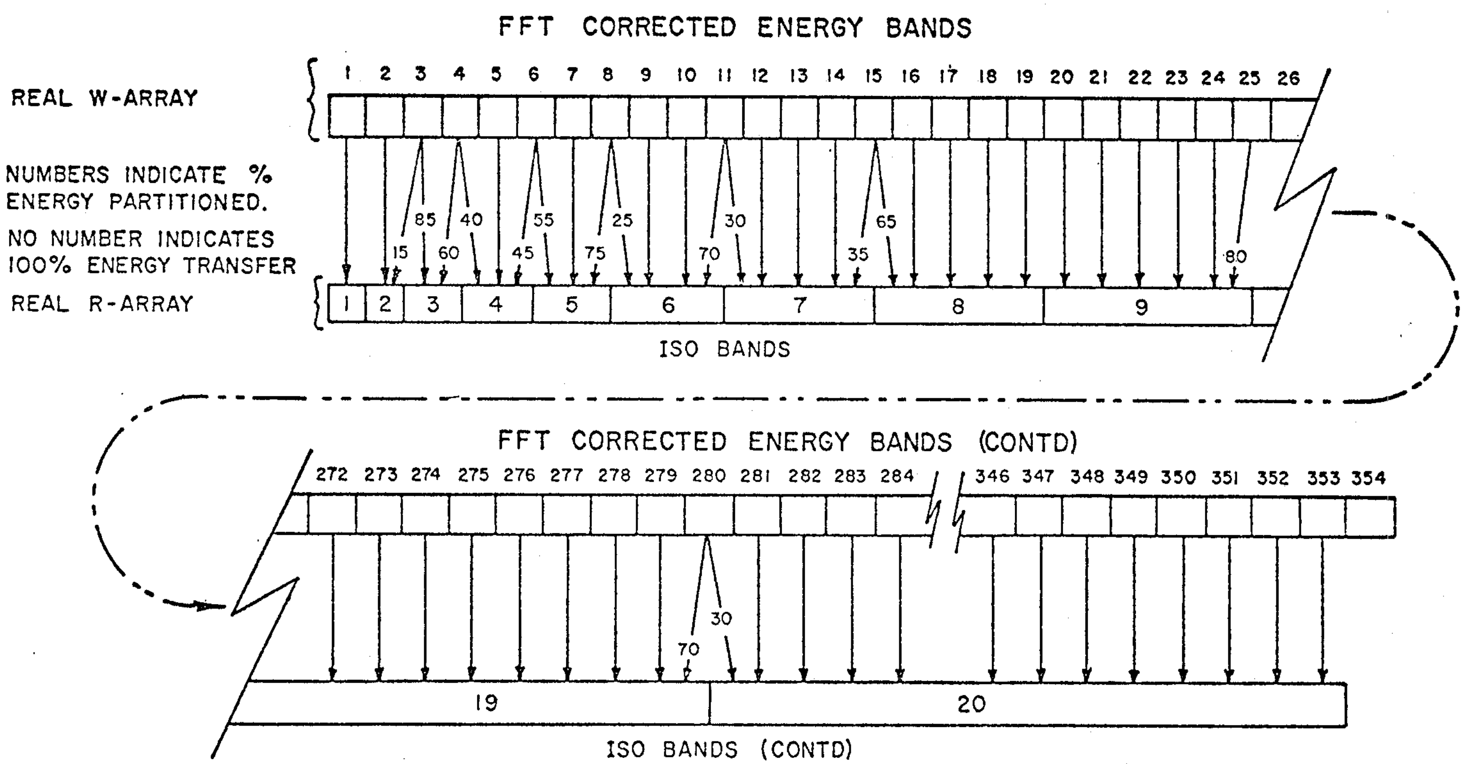


Figure A5. Procedure for Partitioning from W-Array to R-Array

The mathematical representation of the response is given by

$$H(f) = \frac{f_o^2}{-f^2 - 2ibf_o f + f_o^2}$$

Here, H(f) is the accelerometer frequency response, and f is the frequency in hertz. Of primary interest is power response which is given by

$$|H(f)|^2 = \frac{f_o^4}{f^4 - 2(1 - 2b^2)f_o^2 f^2 + f_o^4}$$

The desired correction to the energy data is the inverse of this which is given by

$$P(f) = |H(f)|^{-2} = \frac{f^4 - 2(1 - 2b^2)f_o^2 f^2 + f_o^4}{f_o^4}$$

Correction is effected by evaluating the above for the center frequency of the corresponding FFT output bin. Multiplication of the above expression with the indicated energy value of the bin gives a corrected level. Note that factors f_o and b may be different for each of the three accelerometer axes.

2.2 CONVERSION OF ACCELERATION LEVELS TO EXPOSURE TIME

The implementation of the ISO standards consists of determining the rms acceleration levels for each of the 20 ISO frequency bands in each of the three directions--vertical, lateral and longitudinal. These rms levels are the square roots of the quantities determined by the partitioning process described in the previous section. By using the graphs provided in the ISO documentation, these levels can be converted into time intervals.

The time intervals indicate how long a particular acceleration level can be tolerated before the vibration environment becomes unacceptable. Three limits of tolerance are defined, and they correspond to reduced-comfort boundary, fatigue-decreased proficiency boundary, and the exposure limit. The overall quantitative description of the vibration environment is given by the smallest value of all of the times so determined.

The acceleration versus time limit curve appears to be derived on the basis of the Stevens-Power Law. We have found that the following mathematical expression fits very well when appropriate values of t_o and q are found:

$$t = t_o \left[\left(\frac{\alpha a_o}{a} \right)^{q} - 1 \right]$$

where

a = one of the acceleration levels from one of the ISO bands and for one of the three directions (a total of 60 are generated)

a_o = the zero time acceleration limit defined for each ISO band and for each direction

t = corresponding exposure time

t_o = constant = $\begin{cases} 0.6 \text{ for vertical} \\ 0.48 \text{ for lateral and longitudinal} \end{cases}$

q = constant = $\begin{cases} 1.16 \text{ for vertical} \\ 1.31 \text{ for lateral and longitudinal} \end{cases}$

α = scaling sensitivity factor and
= 2.0 to determine the exposure limit
= 1.0 to determine fatigue-decreased proficiency boundary
= 0.315 to determine reduced-comfort boundary.

Two special cases of this analytic procedure require attention:

- The case where $\left(\frac{\alpha a_o}{a}\right)$ is less than 1 for which t is set equal to 0.

- Calculated exposure time greater than 24 hours is not interpreted, since these values are not defined in the ISO standard.

2.3 STATISTICAL CONSIDERATIONS AND CONFIDENCE LIMITS

The typical vibration environment in a vehicle can be a combination of random, periodic, and a third process best described as randomly modulated periodic. Superposed on these may be events that are neither deterministic nor random. Nor is there a guarantee that any of these random processes has stationary statistics. In this scenario, the question arises as to how reliable the data really are.

The data that are processed are drawn from this environment, and are analyzed using the FFT operation, which is essentially a form of narrowband filtering. Under these circumstances two questions must be resolved:

- What are the confidence limits of the FFT output?

- What can be done to improve those confidence limits?

2.3.1 THE PROBLEM

The time signal that describes the ride environment is the composite of several different processes, including random and periodic deterministic elements. Unfortunately, little is known about the true statistical makeup of these signals. However, they depend on a number of diverse sources, such as guideway geometry, vehicle suspension design, vehicle operating characteristics, and onboard vibrating equipment.

Of interest are the periodic and random elements, since these represent extrema in estimating time series statistics from spectrum theory. For a random series, the spectral ordinate is distributed as χ^2 with one degree of freedom. For this case, the standard error is of the order of the spectral ordinate itself. For a periodic deterministic process whose period is much less than T (4 seconds), the standard error is virtually nonexistent. It can be assumed that the actual distribution of ride quality spectral coordinates will lie somewhere between these two extremes, provided the statistics are reasonably stationary.

It is important to realize that the problem of reliability exists with the individual FFT spectral estimators. In partitioning the FFT components into the 20 ISO bands, spectral estimators are added together. In the case of the low-frequency ISO bands, only a few spectral components (somethimes just one) may be used, which means that the problem of reliability is undiminished here. For the higher ISO frequencies, many spectral estimators are combined to form a new ordinate. The standard error of this ordinate, assuming a random input process, will be a small fraction of the standard error of the individual spectral ordinates.

2.3.2 METHOD OF SOLUTION

In the previous section, the standard error of the ISO bands was reduced at the higher frequencies where more FFT components are combined. There is a general rule that applies to additive combinations of indpendent estimators that are governed by the same statistical process. This rule states that the standard error of the new estimator becomes progressively smaller, when compared to the individual estimators, as more of these estimators are additively combined. This suggests that the fluctuation of the uncertainty attributed to the lower frequency ISO bands can be reduced by taking M nonoverlapping time records of length T. The ISO mean square levels are computed by summing the corresponding estimators and then dividing by M.

In the case where the vibration environment is stationary, the uncertainty of the ISO mean square levels is reduced by the factor M. More generally, if w_o is the expected value of each FFT-derived spectral ordinate, then the standard error for the mean square acceleration in the mth ISO band is given by σ_m as follows:

$$\sigma_m = \frac{1}{\sqrt{4M\delta_m}} w_o$$

Likewise, the standard error of the rms level in the mth ISO band is given by σ_m' as follows:

$$\sigma_m' \simeq \frac{1}{2\sqrt{4M\delta_m}} \sqrt{w_o}$$

Note that the quantity $4M\delta_m$ is the time-bandwidth product. This formulation is in agreement with the theory of rms metering of random signals, where the fluctuation of the meter diminishes as the time-bandwidth product is increased.

2.3.3 CONFIDENCE LIMITS

The procedure of combining corresponding spectral ordinates from different time records is known as stacking. The stacking procedure gives ordinates that have lower levels of fluctuations and that approach the actual statistical levels of the stationary time series. Nonetheless, there are still some residual fluctuation and uncertainty in the results. Therefore, reasonable upper and lower confidence bounds must be placed on the ISO time limits computed from the rms acceleration levels.

One method of doing this is to consider the mean square level of the mth ISO band, given as p_m, from which is computed the expected rms level r_m as

$$r_m = \sqrt{p_m}$$

Then

$$\lambda_m^u = \sqrt{p_m + \beta\sigma_m}$$

is computed, and

$$\lambda_m^\ell = \sqrt{p_m - \alpha\sigma_m}$$

which are the upper and lower confidence limits of the rms level. The constants β and α are chosen to give appropriate levels of confidence. At present, β and α are chosen arbitrarily to be equal to 1.

Two methods exist for computing σ_m. These are:

- The estimation procedure given above.
- Use of stacking statistics to generate estimates.

Both options are provided in the algorithm.

The question arises as to which option should be used for computing σ_m; and, given the value for σ_m, what values of β and α should be used for computing confidence limits. As mentioned previously, statistical theory of the ride quality environment is not well established. Also, it is not known how the p_m ordinates will be distributed. The best that can be done is to apply general guidelines from the theory of random variables. These are:

- Where m is small, say 5 or 6, and where the statistics are reasonably stationary, a random process can be assumed as the worst case. the p_m ordinate is then distributed as χ^2 with $4M\delta_m$ degrees of freedom. From this assumption, appropriate values of β and α can be determined to give appropriate levels of confidence (for example, 90 percent, 95 percent, 99 percent, etc).

- Where m is large, say 10 or more, where there is a reasonably good sampling of data, and where there are no distinctive events, σ_m values can be computed from the data without worrying about how the data are distributed. This is important since the data to be dealt with are known to have features which conflict with the assumption of randomness. These include periodic deterministic components, resonant peaks, and events that are not stationary.

3.0 PROGRAM DESCRIPTION

This section contains general and detailed descriptions of the computer program developed to implement ISO Standard 2631. This program is called ISO.

3.1 GENERAL DESCRIPTION

The ISO program calculates, according to the ISO standard, exposure times for three levels of ride evaluation (exposure limit, fatigue-decreased proficiency, and reduced comfort) from acceleration data (measured in three mutually orthogonal directions). The program is designed to accept acceleration data for the three directions in digital form. The digital data represent the output of accelerometers sampled at a 128-Hz rate and antialiasing filters at 20-Hz.

As illustrated in Figure A6, the program, after initiation and parameter setup, transforms each time sample block into its frequency and power density spectral representation; corrects for accelerometer variations; and regroups and sums the power into bands corresponding to the ISO standard bands. After processing the selected number of samples, the program computes upper and lower confidence limits (plus the minus one standard deviation). One of two methods can be selected for this computation. Option 1 uses the time and bandwidth, and Option 2 used actual data for calculating the standard deviation. Finally, the time limits are computed for each frequency band and each direction. Both expected values, and upper and lower confidence limit values are computed. The minimum exposure times for each direction and the ISO band in which they occurred are then reported (see Section 3.2.2).

PAGE 20.

FIG A6

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3.2 DETAILED DESCRIPTION

In this section the main program and subroutines are described in detail. The program was written for the Raytheon 500, a minicomputer with its memory organized in 2,048-word pages. As a result, the program is stacked into subroutines that do not exceed one page. The dotted lines in Figure A6 indicate separate pages which are called subroutines but which are actually extensions of the main routine and will discussed as such.

3.2.1 Input

Input to the program is from cards and magnetic tape. The input from the cards defines the natural frequency and damping factors for the accelerometer, the output format to be used, and information to select the proper records of data from the magentic tape. The tape contains the digitized accelerometer signals. The tape is organized into files. Each file contains a number of records, and each record contains 128 scans. A scan is made up of seven 16-bit words. Within a scan, the fifth word represents the vertical acceleration, the sixth work the longitudinal acceleration, and the seventh word the lateral acceleration. Only 12 bits of the 16-bit word are used to represent the accelerometer signal. This means that the signal is digitized into 2^{12} = 4,096 states.

Since the data are digitized at a 128-Hz rate, each record represents 1 second of data. The ISO program is designed to read in 4 seconds (one block) of data at a time and perform the stacking operation for sequential blocks of data.

3.2.1.1 Card Input

The first input card defines the natural frequency and damping factor of the accelerometers. The first three values represent the damping factor of the longitudinal, lateral, and vertical accelerometers, respectively. The next three values represent the corresponding natural frequencies of the accelerometers. The format of this card is 6F12.1.

The remaining input cards (one per pass of the program) define the output options and data to be processed. The format of these cards is 4I5, as follows:

Contents: IOPT, NSKIP, IREC, N

IOPT = 1 statistics by option 1, minimum printout
= 3 statistics by option 1, maximum printout
= 2 statistics by option 2, minimum printout
= 4 statistics by option 2, maximum printout
= 9 stop

NSKIP = files to skip (e.g., to process file 3, skip 2 files)

IREC = blocks to skip (e.g., to process 2nd minute of file, skip 15 records)

N = blocks to process (15 = 1 minute)

After each pass of the program, the tape is given a rewind command. A value of IOPT = 9 will stop the program.

For the input cards, the damping factor for all three accelerometers is 0.7, and the natural frequency is 1000 Hz. The first pass card (Card 2) will allow the first 15 blocks of data on the first file to be processed. Card 3 will cause the first 15 blocks of data to be skipped and allow the next 15 blocks of data to be processed. Card 4 will allow the first 30 blocks of data to be processed. The fifth card will stop the program.

Card 1	0.7		0.7		0.7	1000	1000	1000
Card 2	4	0	0	15				
Card 3	4	0	15	15				
Card 4	4	0	0	30				
Card 5	9							

3.2.1.2 Tape Input

The data are in 12-bit format converted to accelerometer level in g's by the program.

3.2.1.3 Test Data Input

If TEST = TRUE is substituted for TEST = FALSE in the program listing, test data will be generated to replace the data usually read from the tape. The test data consist of a 2-g spike for the longitudinal accelerometer signal; a 0.25-g, 1-Hz sine wave for the lateral accelerometer signal; and a 0.75-g, 64-Hz sine wave for the vertical accelerometer signal.

3.2.2 Output

Three forms of output are available from the program. These forms are referred to as the ISO debug output, the normal output, and the sample output. Each is described below.

3.2.2.1 ISO Debug Output

If DEBUG = TRUE is substituted for DEBUG = FALSE in the program, intermediate data will be printed out during the execution of the program. These data include:

- Accelerometer correction factors.
- Band limits and mechanics for grouping into ISO bands.
- Reference acceleration levels for ISO bands.

- Input data.
- Output of FFT operation.
- Power levels in ISO bands.
- Standard deviation computed using time bandwidth.

3.2.2.2 Normal Output

Normal operation of the program provides for the output to include:

- The rms accelerations (computed in g's and in meters per second squared) in three directions with expected values and upper and lower confidence limit values.
- The reduced-comfort boundary for all bands and directions.
- The minimum reduced-comfort boundary with the band at which it occurred.

When output Option 3 or 4 is chosen, the data are augmented with the exposure times for the fatigue and exposure criteria.

APPENDIX B

SAMPLE OUTPUT

P R O B A B I L I T Y D E N S I T Y E S T I M A T E

FILE07▩▩ TEST 23A,B MSG 191-211 COACH 60 MPH BAL

FILE 7 TEST 23A MSG 194-199 REC 30-86

7168. SCANS

RAD/SEC/SEC	ROLL	RAD/SEC/SEC	PITCH	RAD/SEC/SEC	YAW	G'S	LONG	G'S	VERT	G'S	LAT
-4.80	0.00000	-0.96	0.00000	-0.96	0.00000	-0.96	0.00000	-0.96	0.00000	-0.96	0.00000
-4.60	0.00000	-0.92	0.00000	-0.92	0.00000	-0.92	0.00000	-0.92	0.00000	-0.92	0.00000
-4.40	0.00000	-0.88	0.00000	-0.88	0.00000	-0.88	0.00000	-0.88	0.00000	-0.88	0.00000
-4.20	0.00000	-0.84	0.00000	-0.84	0.00000	-0.84	0.00000	-0.84	0.00000	-0.84	0.00000
-4.00	0.00000	-0.80	0.00000	-0.80	0.00000	-0.80	0.00000	-0.80	0.00000	-0.80	0.00000
-3.80	0.00000	-0.76	0.00000	-0.76	0.00000	-0.76	0.00000	-0.76	0.00000	-0.76	0.00000
-3.60	0.00000	-0.72	0.00000	-0.72	0.00000	-0.72	0.00000	-0.72	0.00000	-0.72	0.00000
-3.40	0.00000	-0.68	0.00000	-0.68	0.00000	-0.68	0.00000	-0.68	0.00000	-0.68	0.00000
-3.20	0.00000	-0.64	0.00000	-0.64	0.00000	-0.64	0.00000	-0.64	0.00000	-0.64	0.00000
-3.00	0.00000	-0.60	0.00000	-0.60	0.00000	-0.60	0.00000	-0.60	0.00000	-0.60	0.00000
-2.90	0.00000	-0.58	0.00000	-0.58	0.00000	-0.58	0.00000	-0.58	0.00000	-0.58	0.00000
-2.80	0.00000	-0.56	0.00000	-0.56	0.00000	-0.56	0.00000	-0.56	0.00000	-0.56	0.00000
-2.70	0.00000	-0.54	0.00000	-0.54	0.00000	-0.54	0.00000	-0.54	0.00000	-0.54	0.00000
-2.60	0.00000	-0.52	0.00000	-0.52	0.00000	-0.52	0.00000	-0.52	0.00000	-0.52	0.00000
-2.50	0.00000	-0.50	0.00000	-0.50	0.00000	-0.50	0.00000	-0.50	0.00000	-0.50	0.00000
-2.40	0.00000	-0.48	0.00000	-0.48	0.00000	-0.48	0.00000	-0.48	0.00000	-0.48	0.00000
-2.30	0.00000	-0.46	0.00000	-0.46	0.00000	-0.46	0.00000	-0.46	0.00000	-0.46	0.00000
-2.20	0.00000	-0.44	0.00000	-0.44	0.00000	-0.44	0.00000	-0.44	0.00000	-0.44	0.00000
-2.10	0.00000	-0.42	0.00000	-0.42	0.00000	-0.42	0.00000	-0.42	0.00000	-0.42	0.00000
-2.00	0.00000	-0.40	0.00000	-0.40	0.00000	-0.40	0.00000	-0.40	0.00000	-0.40	0.00000
-1.95	0.00000	-0.39	0.00000	-0.39	0.00000	-0.39	0.00000	-0.39	0.00000	-0.39	0.00000
-1.90	0.00000	-0.38	0.00000	-0.38	0.00000	-0.38	0.00000	-0.38	0.00000	-0.38	0.00000
-1.85	0.00000	-0.37	0.00000	-0.37	0.00000	-0.37	0.00000	-0.37	0.00000	-0.37	0.00000
-1.80	0.00000	-0.36	0.00000	-0.36	0.00000	-0.36	0.00000	-0.36	0.00000	-0.36	0.00000
-1.75	0.00000	-0.35	0.00000	-0.35	0.00000	-0.35	0.00000	-0.35	0.00000	-0.35	0.00000
-1.70	0.00000	-0.34	0.00000	-0.34	0.00000	-0.34	0.00000	-0.34	0.00000	-0.34	0.00000
-1.65	0.00000	-0.33	0.00000	-0.33	0.00000	-0.33	0.00000	-0.33	0.00000	-0.33	0.00000
-1.60	0.00000	-0.32	0.00000	-0.32	0.00000	-0.32	0.00000	-0.32	0.00000	-0.32	0.00000
-1.55	0.00000	-0.31	0.00000	-0.31	0.00000	-0.31	0.00000	-0.31	0.00000	-0.31	0.00000
-1.50	0.00000	-0.30	0.01395	-0.30	0.00000	-0.30	0.00000	-0.30	0.00000	-0.30	0.00000
-1.45	0.00000	-0.29	0.01395	-0.29	0.00000	-0.29	0.00000	-0.29	0.00000	-0.29	0.00000
-1.40	0.00000	-0.28	0.00000	-0.28	0.00000	-0.28	0.00000	-0.28	0.00000	-0.28	0.00000
-1.35	0.00000	-0.27	0.01395	-0.27	0.00000	-0.27	0.00000	-0.27	0.00000	-0.27	0.00000
-1.30	0.00000	-0.26	0.00000	-0.26	0.00000	-0.26	0.00000	-0.26	0.00000	-0.26	0.00000
-1.25	0.00000	-0.25	0.02790	-0.25	0.00000	-0.25	0.00000	-0.25	0.00000	-0.25	0.00000
-1.20	0.00000	-0.24	0.13951	-0.24	0.00000	-0.24	0.00000	-0.24	0.00000	-0.24	0.00000
-1.15	0.00000	-0.23	0.12556	-0.23	0.00000	-0.23	0.00000	-0.23	0.00000	-0.23	0.00000
-1.10	0.00000	-0.22	0.19531	-0.22	0.00000	-0.22	0.00000	-0.22	0.00000	-0.22	0.00000
-1.05	0.00000	-0.21	0.16741	-0.21	0.00000	-0.21	0.00000	-0.21	0.00000	-0.21	0.00000
-1.00	0.00000	-0.20	0.37667	-0.20	0.00000	-0.20	0.00000	-0.20	0.00000	-0.20	0.00000
-0.95	0.00000	-0.19	0.41853	-0.19	0.00000	-0.19	0.00000	-0.19	0.00000	-0.19	0.00000
-0.90	0.00000	-0.18	0.50223	-0.18	0.00000	-0.18	0.00000	-0.18	0.00000	-0.18	0.00000
-0.85	0.00000	-0.17	0.73940	-0.17	0.00000	-0.17	0.00000	-0.17	0.00000	-0.17	0.00000
-0.80	0.00000	-0.16	1.01842	-0.16	0.00000	-0.16	0.00000	-0.16	0.00000	-0.16	0.00000
-0.75	0.00000	-0.15	1.24163	-0.15	0.00000	-0.15	0.00000	-0.15	0.00000	-0.15	0.00000
-0.70	0.00000	-0.14	1.11607	-0.14	0.00000	-0.14	0.00000	-0.14	0.00000	-0.14	0.00000
-0.65	0.00000	-0.13	1.[illegible]942	-0.13	0.00000	-0.13	0.00000	-0.13	0.00000	-0.13	0.00000
-0.60	0.00000	-0.12	1.52065	-0.12	0.00000	-0.12	0.00000	-0.12	0.00000	-0.12	0.00000
-0.55	0.00000	-0.11	1.74386	-0.11	0.00000	-0.11	0.00000	-0.11	0.00000	-0.11	0.00000
-0.50	0.00000	-0.10	2.02788	-0.10	0.00000	-0.10	0.00000	-0.10	0.00000	-0.10	0.00000
-0.45	0.00000	-0.09	2.42746	-0.09	0.00000	-0.09	0.00000	-0.09	0.00000	-0.09	0.00000
-0.40	0.00000	-0.08	2.72042	-0.08	0.00000	-0.08	0.00000	-0.08	0.00000	-0.08	0.00000
-0.35	0.00000	-0.07	3.18000	-0.07	0.00000	-0.07	0.00000	-0.07	0.00000	-0.07	0.00000
-0.30	0.00558	-0.06	3.37612	-0.06	0.00000	-0.06	0.00000	-0.06	0.00000	-0.06	0.00000
-0.25	0.06975	-0.05	4.01786	-0.05	0.04185	-0.05	0.00000	-0.05	0.02790	-0.05	0.00000
-0.20	0.26228	-0.04	3.59933	-0.04	0.09766	-0.04	0.00000	-0.04	0.18136	-0.04	0.00000
-0.15	0.80636	-0.03	3.85045	-0.03	1.31138	-0.03	0.05580	-0.03	1.08817	-0.03	0.46033
-0.10	1.59419	-0.02	4.63170	-0.02	6.50112	-0.02	0.96261	-0.02	4.95257	-0.02	2.76228
-0.05	3.1[illegible]	-0.01	4.81306	-0.01	16.[illegible]	-0.01	11.81641	-0.01	15.45759	-0.01	14.70424

P R O B A B I L I T Y   D E N S I T Y   E S T I M A T E

0.00	4.17132	-0.00	4.58984	-0.00	25.08371	-0.00	39.38337	-0.00	29.57589	-0.00	33.13337
0.05	3.97321	0.01	4.19922	0.01	25.83706	0.01	35.56083	0.01	26.52065	0.01	31.87779
0.10	2.96875	0.02	4.75725	0.02	16.36440	0.02	10.57478	0.02	14.96931	0.02	13.03013
0.15	1.78571	0.03	4.31083	0.03	6.06864	0.03	1.45089	0.03	5.41295	0.03	3.43192
0.20	0.80915	0.04	4.00391	0.04	1.38114	0.04	0.18136	0.04	1.53460	0.04	0.53013
0.25	0.30134	0.05	3.52958	0.05	0.41853	0.05	0.01395	0.05	0.23717	0.05	0.05975
0.30	0.06975	0.06	3.80859	0.06	0.04185	0.06	0.00000	0.06	0.04185	0.06	0.00000
0.35	0.01395	0.07	3.12500	0.07	0.00000	0.07	0.00000	0.07	0.00000	0.07	0.00000
0.40	0.00837	0.08	2.95759	0.08	0.00000	0.08	0.00000	0.08	0.00000	0.08	0.00000
0.45	0.00279	0.09	3.02734	0.09	0.00000	0.09	0.00000	0.09	0.00000	0.09	0.00000
0.50	0.00000	0.10	2.51116	0.10	0.00000	0.10	0.00000	0.10	0.00000	0.10	0.00000
0.55	0.00000	0.11	1.99498	0.11	0.00000	0.11	0.00000	0.11	0.00000	0.11	0.00000
0.60	0.00000	0.12	2.06473	0.12	0.00000	0.12	0.00000	0.12	0.00000	0.12	0.00000
0.65	0.00000	0.13	1.53460	0.13	0.00000	0.13	0.00000	0.13	0.00000	0.13	0.00000
0.70	0.00000	0.14	1.42299	0.14	0.00000	0.14	0.00000	0.14	0.00000	0.14	0.00000
0.75	0.00000	0.15	1.43694	0.15	0.00000	0.15	0.00000	0.15	0.00000	0.15	0.00000
0.80	0.00000	0.16	1.06027	0.16	0.00000	0.16	0.00000	0.16	0.00000	0.16	0.00000
0.85	0.00000	0.17	0.83705	0.17	0.00000	0.17	0.00000	0.17	0.00000	0.17	0.00000
0.90	0.00000	0.18	0.71150	0.18	0.00000	0.18	0.00000	0.18	0.00000	0.18	0.00000
0.95	0.00000	0.19	0.57199	0.19	0.00000	0.19	0.00000	0.19	0.00000	0.19	0.00000
1.00	0.00000	0.20	0.43248	0.20	0.00000	0.20	0.00000	0.20	0.00000	0.20	0.00000
1.05	0.00000	0.21	0.29297	0.21	0.00000	0.21	0.00000	0.21	0.00000	0.21	0.00000
1.10	0.00000	0.22	0.22321	0.22	0.00000	0.22	0.00000	0.22	0.00000	0.22	0.00000
1.15	0.00000	0.23	0.22321	0.23	0.00000	0.23	0.00000	0.23	0.00000	0.23	0.00000
1.20	0.00000	0.24	0.16741	0.24	0.00000	0.24	0.00000	0.24	0.00000	0.24	0.00000
1.25	0.00000	0.25	0.08371	0.25	0.00000	0.25	0.00000	0.25	0.00000	0.25	0.00000
1.30	0.00000	0.26	0.11161	0.26	0.00000	0.26	0.00000	0.26	0.00000	0.26	0.00000
1.35	0.00000	0.27	0.04185	0.27	0.00000	0.27	0.00000	0.27	0.00000	0.27	0.00000
1.40	0.00000	0.28	0.04185	0.28	0.00000	0.28	0.00000	0.28	0.00000	0.28	0.00000
1.45	0.00000	0.29	0.01395	0.29	0.00000	0.29	0.00000	0.29	0.00000	0.29	0.00000
1.50	0.00000	0.30	0.00000	0.30	0.00000	0.30	0.00000	0.30	0.00000	0.30	0.00000
1.55	0.00000	0.31	0.01395	0.31	0.00000	0.31	0.00000	0.31	0.00000	0.31	0.00000
1.60	0.00000	0.32	0.01395	0.32	0.00000	0.32	0.00000	0.32	0.00000	0.32	0.00000
1.65	0.00000	0.33	0.00000	0.33	0.00000	0.33	0.00000	0.33	0.00000	0.33	0.00000
1.70	0.00000	0.34	0.00000	0.34	0.00000	0.34	0.00000	0.34	0.00000	0.34	0.00000
1.75	0.00000	0.35	0.00000	0.35	0.00000	0.35	0.00000	0.35	0.00000	0.35	0.00000
1.80	0.00000	0.36	0.00000	0.36	0.00000	0.36	0.00000	0.36	0.00000	0.36	0.00000
1.85	0.00000	0.37	0.00000	0.37	0.00000	0.37	0.00000	0.37	0.00000	0.37	0.00000
1.90	0.00000	0.38	0.00000	0.38	0.00000	0.38	0.00000	0.38	0.00000	0.38	0.00000
1.95	0.00000	0.39	0.00000	0.39	0.00000	0.39	0.00000	0.39	0.00000	0.39	0.00000
2.00	0.00000	0.40	0.00000	0.40	0.00000	0.40	0.00000	0.40	0.00000	0.40	0.00000
2.10	0.00000	0.42	0.00000	0.42	0.00000	0.42	0.00000	0.42	0.00000	0.42	0.00000
2.20	0.00000	0.44	0.00000	0.44	0.00000	0.44	0.00000	0.44	0.00000	0.44	0.00000
2.30	0.00000	0.46	0.00000	0.46	0.00000	0.46	0.00000	0.46	0.00000	0.46	0.00000
2.40	0.00000	0.48	0.00000	0.48	0.00000	0.48	0.00000	0.48	0.00000	0.48	0.00000
2.50	0.00000	0.50	0.00000	0.50	0.00000	0.50	0.00000	0.50	0.00000	0.50	0.00000
2.60	0.00000	0.52	0.00000	0.52	0.00000	0.52	0.00000	0.52	0.00000	0.52	0.00000
2.70	0.00000	0.54	0.00000	0.54	0.00000	0.54	0.00000	0.54	0.00000	0.54	0.00000
2.80	0.00000	0.56	0.00000	0.56	0.00000	0.56	0.00000	0.56	0.00000	0.56	0.00000
2.90	0.00000	0.58	0.00000	0.58	0.00000	0.58	0.00000	0.58	0.00000	0.58	0.00000
3.00	0.00000	0.60	0.00000	0.60	0.00000	0.60	0.00000	0.60	0.00000	0.60	0.00000
3.20	0.00000	0.64	0.00000	0.64	0.00000	0.64	0.00000	0.64	0.00000	0.64	0.00000
3.40	0.00000	0.68	0.00000	0.68	0.00000	0.68	0.00000	0.68	0.00000	0.68	0.00000
3.60	0.00000	0.72	0.00000	0.72	0.00000	0.72	0.00000	0.72	0.00000	0.72	0.00000
3.80	0.00000	0.76	0.00000	0.76	0.00000	0.76	0.00000	0.76	0.00000	0.76	0.00000
4.00	0.00000	0.80	0.00000	0.80	0.00000	0.80	0.00000	0.80	0.00000	0.80	0.00000
4.20	0.00000	0.84	0.00000	0.84	0.00000	0.84	0.00000	0.84	0.00000	0.84	0.00000
4.40	0.00000	0.88	0.00000	0.88	0.00000	0.88	0.00000	0.88	0.00000	0.88	0.00000
4.60	0.00000	0.92	0.00000	0.92	0.00000	0.92	0.00000	0.92	0.00000	0.92	0.00000
4.80	0.00000	0.96	0.00000	0.96	0.00000	0.96	0.00000	0.96	0.00000	0.96	0.00000
5.00	0.00000	1.00	0.00000	1.00	0.00000	1.00	0.00000	1.00	0.00000	1.00	0.00000
ST. DEV.	0.09716		0.08942		0.01484		0.00978		0.01408		0.01180

DISTRIBUTION FUNCTION ESTIMATE

FILE07▒▒ TEST 23A,B MSG 191-211 COACH 60 MPH BAL

FILE 7 TEST 23A MSG 194-199 REC 30-86

7168. SCANS

ROLL RAD/SEC/SEC		PITCH RAD/SEC/SEC		YAW RAD/SEC/SEC		LONG G'S		VERT G'S		LAT G'S	
-4.80	0.00000	-0.96	0.00000	-0.96	0.00000	-0.96	0.00000	-0.96	0.00000	-0.96	0.00000
-4.60	0.00000	-0.92	0.00000	-0.92	0.00000	-0.92	0.00000	-0.92	0.00000	-0.92	0.00000
-4.40	0.00000	-0.88	0.00000	-0.88	0.00000	-0.88	0.00000	-0.88	0.00000	-0.88	0.00000
-4.20	0.00000	-0.84	0.00000	-0.84	0.00000	-0.84	0.00000	-0.84	0.00000	-0.84	0.00000
-4.00	0.00000	-0.80	0.00000	-0.80	0.00000	-0.80	0.00000	-0.80	0.00000	-0.80	0.00000
-3.80	0.00000	-0.76	0.00000	-0.76	0.00000	-0.76	0.00000	-0.76	0.00000	-0.76	0.00000
-3.60	0.00000	-0.72	0.00000	-0.72	0.00000	-0.72	0.00000	-0.72	0.00000	-0.72	0.00000
-3.40	0.00000	-0.68	0.00000	-0.68	0.00000	-0.68	0.00000	-0.68	0.00000	-0.68	0.00000
-3.20	0.00000	-0.64	0.00000	-0.64	0.00000	-0.64	0.00000	-0.64	0.00000	-0.64	0.00000
-3.00	0.00000	-0.60	0.00000	-0.60	0.00000	-0.60	0.00000	-0.60	0.00000	-0.60	0.00000
-2.90	0.00000	-0.58	0.00000	-0.58	0.00000	-0.58	0.00000	-0.58	0.00000	-0.58	0.00000
-2.80	0.00000	-0.56	0.00000	-0.56	0.00000	-0.56	0.00000	-0.56	0.00000	-0.56	0.00000
-2.70	0.00000	-0.54	0.00000	-0.54	0.00000	-0.54	0.00000	-0.54	0.00000	-0.54	0.00000
-2.60	0.00000	-0.52	0.00000	-0.52	0.00000	-0.52	0.00000	-0.52	0.00000	-0.52	0.00000
-2.50	0.00000	-0.50	0.00000	-0.50	0.00000	-0.50	0.00000	-0.50	0.00000	-0.50	0.00000
-2.40	0.00000	-0.48	0.00000	-0.48	0.00000	-0.48	0.00000	-0.48	0.00000	-0.48	0.00000
-2.30	0.00000	-0.46	0.00000	-0.46	0.00000	-0.46	0.00000	-0.46	0.00000	-0.46	0.00000
-2.20	0.00000	-0.44	0.00000	-0.44	0.00000	-0.44	0.00000	-0.44	0.00000	-0.44	0.00000
-2.10	0.00000	-0.42	0.00000	-0.42	0.00000	-0.42	0.00000	-0.42	0.00000	-0.42	0.00000
-2.00	0.00000	-0.40	0.00000	-0.40	0.00000	-0.40	0.00000	-0.40	0.00000	-0.40	0.00000
-1.95	0.00000	-0.39	0.00000	-0.39	0.00000	-0.39	0.00000	-0.39	0.00000	-0.39	0.00000
-1.90	0.00000	-0.38	0.00000	-0.38	0.00000	-0.38	0.00000	-0.38	0.00000	-0.38	0.00000
-1.85	0.00000	-0.37	0.00000	-0.37	0.00000	-0.37	0.00000	-0.37	0.00000	-0.37	0.00000
-1.80	0.00000	-0.36	0.00000	-0.36	0.00000	-0.36	0.00000	-0.36	0.00000	-0.36	0.00000
-1.75	0.00000	-0.35	0.00000	-0.35	0.00000	-0.35	0.00000	-0.35	0.00000	-0.35	0.00000
-1.70	0.00000	-0.34	0.00000	-0.34	0.00000	-0.34	0.00000	-0.34	0.00000	-0.34	0.00000
-1.65	0.00000	-0.33	0.00000	-0.33	0.00000	-0.33	0.00000	-0.33	0.00000	-0.33	0.00000
-1.60	0.00000	-0.32	0.00000	-0.32	0.00000	-0.32	0.00000	-0.32	0.00000	-0.32	0.00000
-1.55	0.00000	-0.31	0.00000	-0.31	0.00000	-0.31	0.00000	-0.31	0.00000	-0.31	0.00000
-1.50	0.00000	-0.30	0.00014	-0.30	0.00000	-0.30	0.00000	-0.30	0.00000	-0.30	0.00000
-1.45	0.00000	-0.29	0.00028	-0.29	0.00000	-0.29	0.00000	-0.29	0.00000	-0.29	0.00000
-1.40	0.00000	-0.28	0.00028	-0.28	0.00000	-0.28	0.00000	-0.28	0.00000	-0.28	0.00000
-1.35	0.00000	-0.27	0.00042	-0.27	0.00000	-0.27	0.00000	-0.27	0.00000	-0.27	0.00000
-1.30	0.00000	-0.26	0.00042	-0.26	0.00000	-0.26	0.00000	-0.26	0.00000	-0.26	0.00000
-1.25	0.00000	-0.25	0.00070	-0.25	0.00000	-0.25	0.00000	-0.25	0.00000	-0.25	0.00000
-1.20	0.00000	-0.24	0.00209	-0.24	0.00000	-0.24	0.00000	-0.24	0.00000	-0.24	0.00000
-1.15	0.00000	-0.23	0.00335	-0.23	0.00000	-0.23	0.00000	-0.23	0.00000	-0.23	0.00000
-1.10	0.00000	-0.22	0.00530	-0.22	0.00000	-0.22	0.00000	-0.22	0.00000	-0.22	0.00000
-1.05	0.00000	-0.21	0.00698	-0.21	0.00000	-0.21	0.00000	-0.21	0.00000	-0.21	0.00000
-1.00	0.00000	-0.20	0.01074	-0.20	0.00000	-0.20	0.00000	-0.20	0.00000	-0.20	0.00000
-0.95	0.00000	-0.19	0.01493	-0.19	0.00000	-0.19	0.00000	-0.19	0.00000	-0.19	0.00000
-0.90	0.00000	-0.18	0.01995	-0.18	0.00000	-0.18	0.00000	-0.18	0.00000	-0.18	0.00000
-0.85	0.00000	-0.17	0.02734	-0.17	0.00000	-0.17	0.00000	-0.17	0.00000	-0.17	0.00000
-0.80	0.00000	-0.16	0.03753	-0.16	0.00000	-0.16	0.00000	-0.16	0.00000	-0.16	0.00000
-0.75	0.00000	-0.15	0.04994	-0.15	0.00000	-0.15	0.00000	-0.15	0.00000	-0.15	0.00000
-0.70	0.00000	-0.14	0.06110	-0.14	0.00000	-0.14	0.00000	-0.14	0.00000	-0.14	0.00000
-0.65	0.00000	-0.13	0.07980	-0.13	0.00000	-0.13	0.00000	-0.13	0.00000	-0.13	0.00000
-0.60	0.00000	-0.12	0.09501	-0.12	0.00000	-0.12	0.00000	-0.12	0.00000	-0.12	0.00000
-0.55	0.00000	-0.11	0.11244	-0.11	0.00000	-0.11	0.00000	-0.11	0.00000	-0.11	0.00000
-0.50	0.00000	-0.10	0.13267	-0.10	0.00000	-0.10	0.00000	-0.10	0.00000	-0.10	0.00000
-0.45	0.00000	-0.09	0.15695	-0.09	0.00000	-0.09	0.00000	-0.09	0.00000	-0.09	0.00000
-0.40	0.00000	-0.08	0.18415	-0.08	0.00000	-0.08	0.00000	-0.08	0.00000	-0.08	0.00000
-0.35	0.00000	-0.07	0.21596	-0.07	0.00000	-0.07	0.00000	-0.07	0.00000	-0.07	0.00000
-0.30	0.00028	-0.06	0.24972	-0.06	0.00000	-0.06	0.00000	-0.06	0.00000	-0.06	0.00000
-0.25	0.00377	-0.05	0.28990	-0.05	0.00042	-0.05	0.00000	-0.05	0.00028	-0.05	0.00000
-0.20	0.01688	-0.04	0.32589	-0.04	0.00140	-0.04	0.00000	-0.04	0.00209	-0.04	0.00000
-0.15	0.05720	-0.03	0.36440	-0.03	0.01451	-0.03	0.00056	-0.03	0.01297	-0.03	0.00460
-0.10	0.13086	-0.02	0.41071	-0.02	0.07952	-0.02	0.01018	-0.02	0.06250	-0.02	0.03223
-0.05	0.20478	-0.01	0.45884	-0.01	0.24505	-0.01	0.12335	-0.01	0.21708	-0.01	0.17927

DISTRIBUTION FUNCTION ESTIMATE

0.00	0.50335	-0.00	0.50474	-0.00	0.49888	-0.00	0.52218	-0.00	0.51283	-0.00	0.51060
0.05	0.70201	0.01	0.54674	0.01	0.75725	0.01	0.87779	0.01	0.77804	0.01	0.82938
0.10	0.85045	0.02	0.59431	0.02	0.92090	0.02	0.98354	0.02	0.92773	0.02	0.95968
0.15	0.93973	0.03	0.63742	0.03	0.98158	0.03	0.99805	0.03	0.98186	0.03	0.99400
0.20	0.98019	0.04	0.67746	0.04	0.99540	0.04	0.99986	0.04	0.99721	0.04	0.99930
0.25	0.99526	0.05	0.71275	0.05	0.99958	0.05	1.00000	0.05	0.99958	0.05	1.00000
0.30	0.99874	0.06	0.75084	0.06	1.00000	0.06	1.00000	0.06	1.00000	0.06	1.00000
0.35	0.99944	0.07	0.78209	0.07	1.00000	0.07	1.00000	0.07	1.00000	0.07	1.00000
0.40	0.99986	0.08	0.81166	0.08	1.00000	0.08	1.00000	0.08	1.00000	0.08	1.00000
0.45	1.00000	0.09	0.84194	0.09	1.00000	0.09	1.00000	0.09	1.00000	0.09	1.00000
0.50	1.00000	0.10	0.86705	0.10	1.00000	0.10	1.00000	0.10	1.00000	0.10	1.00000
0.55	1.00000	0.11	0.88700	0.11	1.00000	0.11	1.00000	0.11	1.00000	0.11	1.00000
0.60	1.00000	0.12	0.90764	0.12	1.00000	0.12	1.00000	0.12	1.00000	0.12	1.00000
0.65	1.00000	0.13	0.92299	0.13	1.00000	0.13	1.00000	0.13	1.00000	0.13	1.00000
0.70	1.00000	0.14	0.93722	0.14	1.00000	0.14	1.00000	0.14	1.00000	0.14	1.00000
0.75	1.00000	0.15	0.95159	0.15	1.00000	0.15	1.00000	0.15	1.00000	0.15	1.00000
0.80	1.00000	0.16	0.96219	0.16	1.00000	0.16	1.00000	0.16	1.00000	0.16	1.00000
0.85	1.00000	0.17	0.97056	0.17	1.00000	0.17	1.00000	0.17	1.00000	0.17	1.00000
0.90	1.00000	0.18	0.97768	0.18	1.00000	0.18	1.00000	0.18	1.00000	0.18	1.00000
0.95	1.00000	0.19	0.98340	0.19	1.00000	0.19	1.00000	0.19	1.00000	0.19	1.00000
1.00	1.00000	0.20	0.98772	0.20	1.00000	0.20	1.00000	0.20	1.00000	0.20	1.00000
1.05	1.00000	0.21	0.99065	0.21	1.00000	0.21	1.00000	0.21	1.00000	0.21	1.00000
1.10	1.00000	0.22	0.99288	0.22	1.00000	0.22	1.00000	0.22	1.00000	0.22	1.00000
1.15	1.00000	0.23	0.99512	0.23	1.00000	0.23	1.00000	0.23	1.00000	0.23	1.00000
1.20	1.00000	0.24	0.99679	0.24	1.00000	0.24	1.00000	0.24	1.00000	0.24	1.00000
1.25	1.00000	0.25	0.99763	0.25	1.00000	0.25	1.00000	0.25	1.00000	0.25	1.00000
1.30	1.00000	0.26	0.99874	0.26	1.00000	0.26	1.00000	0.26	1.00000	0.26	1.00000
1.35	1.00000	0.27	0.99916	0.27	1.00000	0.27	1.00000	0.27	1.00000	0.27	1.00000
1.40	1.00000	0.28	0.99958	0.28	1.00000	0.28	1.00000	0.28	1.00000	0.28	1.00000
1.45	1.00000	0.29	0.99972	0.29	1.00000	0.29	1.00000	0.29	1.00000	0.29	1.00000
1.50	1.00000	0.30	0.99972	0.30	1.00000	0.30	1.00000	0.30	1.00000	0.30	1.00000
1.55	1.00000	0.31	0.99986	0.31	1.00000	0.31	1.00000	0.31	1.00000	0.31	1.00000
1.60	1.00000	0.32	1.00000	0.32	1.00000	0.32	1.00000	0.32	1.00000	0.32	1.00000
1.65	1.00000	0.33	1.00000	0.33	1.00000	0.33	1.00000	0.33	1.00000	0.33	1.00000
1.70	1.00000	0.34	1.00000	0.34	1.00000	0.34	1.00000	0.34	1.00000	0.34	1.00000
1.75	1.00000	0.35	1.00000	0.35	1.00000	0.35	1.00000	0.35	1.00000	0.35	1.00000
1.80	1.00000	0.36	1.00000	0.36	1.00000	0.36	1.00000	0.36	1.00000	0.36	1.00000
1.85	1.00000	0.37	1.00000	0.37	1.00000	0.37	1.00000	0.37	1.00000	0.37	1.00000
1.90	1.00000	0.38	1.00000	0.38	1.00000	0.38	1.00000	0.38	1.00000	0.38	1.00000
1.95	1.00000	0.39	1.00000	0.39	1.00000	0.39	1.00000	0.39	1.00000	0.39	1.00000
2.00	1.00000	0.40	1.00000	0.40	1.00000	0.40	1.00000	0.40	1.00000	0.40	1.00000
2.10	1.00000	0.42	1.00000	0.42	1.00000	0.42	1.00000	0.42	1.00000	0.42	1.00000
2.20	1.00000	0.44	1.00000	0.44	1.00000	0.44	1.00000	0.44	1.00000	0.44	1.00000
2.30	1.00000	0.46	1.00000	0.46	1.00000	0.46	1.00000	0.46	1.00000	0.46	1.00000
2.40	1.00000	0.48	1.00000	0.48	1.00000	0.48	1.00000	0.48	1.00000	0.48	1.00000
2.50	1.00000	0.50	1.00000	0.50	1.00000	0.50	1.00000	0.50	1.00000	0.50	1.00000
2.60	1.00000	0.52	1.00000	0.52	1.00000	0.52	1.00000	0.52	1.00000	0.52	1.00000
2.70	1.00000	0.54	1.00000	0.54	1.00000	0.54	1.00000	0.54	1.00000	0.54	1.00000
2.80	1.00000	0.56	1.00000	0.56	1.00000	0.56	1.00000	0.56	1.00000	0.56	1.00000
2.90	1.00000	0.58	1.00000	0.58	1.00000	0.58	1.00000	0.58	1.00000	0.58	1.00000
3.00	1.00000	0.60	1.00000	0.60	1.00000	0.60	1.00000	0.60	1.00000	0.60	1.00000
3.20	1.00000	0.64	1.00000	0.64	1.00000	0.64	1.00000	0.64	1.00000	0.64	1.00000
3.40	1.00000	0.68	1.00000	0.68	1.00000	0.68	1.00000	0.68	1.00000	0.68	1.00000
3.60	1.00000	0.72	1.00000	0.72	1.00000	0.72	1.00000	0.72	1.00000	0.72	1.00000
3.80	1.00000	0.76	1.00000	0.76	1.00000	0.76	1.00000	0.76	1.00000	0.76	1.00000
4.00	1.00000	0.80	1.00000	0.80	1.00000	0.80	1.00000	0.80	1.00000	0.80	1.00000
4.20	1.00000	0.84	1.00000	0.84	1.00000	0.84	1.00000	0.84	1.00000	0.84	1.00000
4.40	1.00000	0.88	1.00000	0.88	1.00000	0.88	1.00000	0.88	1.00000	0.88	1.00000
4.60	1.00000	0.92	1.00000	0.92	1.00000	0.92	1.00000	0.92	1.00000	0.92	1.00000
4.80	1.00000	0.96	1.00000	0.96	1.00000	0.96	1.00000	0.96	1.00000	0.96	1.00000
5.00	1.00000	1.00	1.00000	1.00	1.00000	1.00	1.00000	1.00	1.00000	1.00	1.00000
ST. DEV.	0.00716		0.0[illegible]42		0.01484		0.00978		0.01408		0.01180

TEST 23A,B MSG 191-211 COACH 60 MPH BAL

FILE 7 TEST 23A MSG 194-199 REC 30-86

ROLL RAD/SEC/SEC	PITCH RAD/SEC/SEC	YAW RAD/SEC/SEC	CENTER FREQ		ROLL RAD/SEC/SEC	PITCH RAD/SEC/SEC	YAW RAD/SEC/SEC
0.00000	0.00054	0.00323		LB	0.00430	0.00437	0.00098
0.02519	0.00219	0.00635	6.3 HZ	EV	0.00855	0.00599	0.00133
0.03601	0.00305	0.00838		UB	0.01130	0.00726	0.00160
0.00000	0.00095	0.00140		LB	0.00758	0.01172	0.00161
0.01754	0.00263	0.00373	8.0 HZ	EV	0.02533	0.01537	0.00205
0.02548	0.00360	0.00509		UB	0.03500	0.01830	0.00242
0.01009	0.00252	0.00153		LB	0.02709	0.01855	0.00166
0.02482	0.00491	0.00315	10.0 HZ	EV	0.03385	0.02378	0.00194
0.03362	0.00647	0.00418		UB	0.03948	0.02805	0.00219
0.00847	0.00440	0.00322		LB	0.04270	0.05682	0.00259
0.01799	0.00636	0.00500	12.5 HZ	EV	0.05339	0.07178	0.00317
0.02399	0.00784	0.00530		UB	0.06228	0.08413	0.00366
0.00588	0.00362	0.00356		LB	0.01934	0.03141	0.00196
0.00844	0.00526	0.00525	16.0 HZ	EV	0.02547	0.04195	0.00233
0.01039	0.00651	0.00652		UB	0.03039	0.05034	0.00264
0.00493	0.00179	0.00151		LB	0.02557	0.00730	0.00356
0.00627	0.00269	0.00202	20.0 HZ	EV	0.02985	0.00942	0.00425
0.00737	0.00335	0.00242		UB	0.03360	0.01114	0.00485
0.00340	0.00199	0.00109		LB	0.01098	0.00250	0.00182
0.00631	0.00271	0.00184	25.0 HZ	EV	0.01250	0.00311	0.00216
0.00825	0.00328	0.00236		UB	0.01386	0.00362	0.00244
0.00418	0.00191	0.00108		LB	0.01283	0.00192	0.00128
0.00624	0.00313	0.00152	31.5 HZ	EV	0.01466	0.00242	0.00142
0.00776	0.00399	0.00187		UB	0.01628	0.00283	0.00154

1/3 OCTAVE BANDS - AVERAGE RMS ACCELERATION

TEST 23A,B MSG 191-211 COACH 60 MPH BAL

FILE 7 TEST 23A MSG 194-199 REC 30-86

CENTER FREQ		LONG G'S	VERT G'S	LAT G'S
1.0 HZ	LB	0.00016	0.00111	0.00285
	EV	0.00046	0.00281	0.00431
	UB	0.00064	0.00382	0.00539
1.3 HZ	LB	0.00020	0.00039	0.00096
	EV	0.00059	0.00311	0.00331
	UB	0.00080	0.00438	0.00458
1.6 HZ	LB	0.00049	0.00271	0.00254
	EV	0.00071	0.00437	0.00466
	UB	0.00087	0.00556	0.00608
2.0 HZ	LB	0.00045	0.00232	0.00173
	EV	0.00067	0.00343	0.00357
	UB	0.00084	0.00426	0.00474
2.5 HZ	LB	0.00034	0.00107	0.00085
	EV	0.00064	0.00157	0.00134
	UB	0.00083	0.00194	0.00169
3.1 HZ	LB	0.00052	0.00169	0.00106
	EV	0.00078	0.00225	0.00151
	UB	0.00098	0.00270	0.00185
4.0 HZ	LB	0.00062	0.00118	0.00089
	EV	0.00105	0.00162	0.00135
	UB	0.00135	0.00197	0.00169
5.0 HZ	LB	0.00075	0.00105	0.00094
	EV	0.00118	0.00133	0.00145
	UB	0.00149	0.00155	0.00182
6.3 HZ	LB	0.00105	0.00236	0.00115
	EV	0.00133	0.00291	0.00137
	UB	0.00156	0.00338	0.00156
8.0 HZ	LB	0.00148	0.00492	0.00252
	EV	0.00182	0.00686	0.00364
	UB	0.00211	0.00837	0.00449
10.0 HZ	LB	0.00171	0.00378	0.00246
	EV	0.00225	0.00467	0.00314
	UB	0.00268	0.00542	0.00369
12.5 HZ	LB	0.00446	0.00402	0.00146
	EV	0.00578	0.00511	0.00203
	UB	0.00685	0.00600	0.00248
16.0 HZ	LB	0.00342	0.00227	0.00136
	EV	0.00438	0.00285	0.00167
	UB	0.00516	0.00332	0.00194
20.0 HZ	LB	0.00182	0.00153	0.00181
	EV	0.00207	0.00180	0.00207
	UB	0.00229	0.00203	0.00230
25.0 HZ	LB	0.00104	0.00102	0.00112
	EV	0.00121	0.00119	0.00129
	UB	0.00136	0.00133	0.00143
31.5 HZ	LB	0.00104	0.00108	0.00105
	EV	0.00118	0.00125	0.00117
	UB	0.00131	0.00140	0.00128

TEST 23A,B MSG 191-211 COACH 60 MPH BAL

FILE 7 TEST 23A MSG 194-199 REC 30-86

CENTER FREQ		LONG	LAT	VERT	CENTER FREQ		LONG	LAT	VERT
1.0 HZ	LB	24.0	24.0	24.0	6.3 HZ	LB	24.0	24.0	24.0
	EV	24.0	16.1	24.0		EV	24.0	24.0	24.0
	UB	24.0	11.9	24.0		UB	24.0	24.0	24.0
1.3 HZ	LB	24.0	24.0	24.0	8.0 HZ	LB	24.0	24.0	17.1
	EV	24.0	22.9	24.0		EV	24.0	24.0	11.4
	UB	24.0	14.8	24.0		UB	24.0	24.0	8.9
1.6 HZ	LB	24.0	24.0	24.0	10.0 HZ	LB	24.0	24.0	24.0
	EV	24.0	14.5	24.0		EV	24.0	24.0	23.9
	UB	24.0	10.1	24.0		UB	24.0	24.0	20.1
2.0 HZ	LB	24.0	24.0	24.0	12.5 HZ	LB	24.0	24.0	24.0
	EV	24.0	20.7	24.0		EV	24.0	24.0	24.0
	UB	24.0	14.1	24.0		UB	24.0	24.0	23.3
2.5 HZ	LB	24.0	24.0	24.0	16.0 HZ	LB	24.0	24.0	24.0
	EV	24.0	24.0	24.0		EV	24.0	24.0	24.0
	UB	24.0	24.0	24.0		UB	24.0	24.0	24.0
3.1 HZ	LB	24.0	24.0	24.0	20.0 HZ	LB	24.0	24.0	24.0
	EV	24.0	24.0	24.0		EV	24.0	24.0	24.0
	UB	24.0	24.0	24.0		UB	24.0	24.0	24.0
4.0 HZ	LB	24.0	24.0	24.0	25.0 HZ	LB	24.0	24.0	24.0
	EV	24.0	24.0	24.0		EV	24.0	24.0	24.0
	UB	24.0	24.0	24.0		UB	24.0	24.0	24.0
5.0 HZ	LB	24.0	24.0	24.0	31.5 HZ	LB	24.0	24.0	24.0
	EV	24.0	24.0	24.0		EV	24.0	24.0	24.0
	UB	24.0	24.0	24.0		UB	24.0	24.0	24.0

MINIMA

	LONG	LAT	VERT
EXPOSURE TIME (HRS):	24.0	14.5	11.4
CENTER FREQ (HZ):	1.0	1.6	8.0

P S D L E V E L S (D B)

FREQ(HZ)	ROLL	PITCH	YAW	LONG	VERT	LAT
0.25	-40.0923	-51.5225	-49.0999	-60.6700	-54.7182	-50.4195
0.50	-37.0218	-48.4452	-41.6574	-60.1809	-55.3387	-48.5085
0.75	-29.9127	-47.3658	-41.0946	-59.3617	-49.7660	-43.2426
1.00	-25.9550	-47.1564	-37.9244	-60.6523	-45.0072	-41.2845
1.25	-30.0410	-47.0906	-42.7393	-59.3137	-44.7563	-44.4413
1.50	-27.9464	-42.6370	-47.7283	-58.7065	-44.6304	-42.8054
1.75	-27.3647	-40.7860	-43.7540	-58.4927	-41.0417	-41.5149
2.00	-33.2019	-40.9876	-42.6142	-60.5171	-48.4639	-46.9145
2.25	-37.3672	-39.6729	-41.9857	-60.9021	-54.9827	-52.8290
2.50	-39.1178	-43.9564	-41.7864	-61.4644	-52.6914	-55.7730
2.75	-40.8336	-48.2042	-49.0589	-62.0620	-54.4724	-56.5977
3.00	-43.3934	-48.7817	-51.1797	-59.4980	-52.1144	-56.2942
3.25	-43.1993	-51.4314	-54.7024	-61.9394	-50.6393	-54.5160
3.50	-42.1352	-51.7746	-55.1452	-61.1302	-51.7689	-54.1855
3.75	-43.4178	-49.8867	-56.1788	-60.2612	-54.1013	-57.0313
4.00	-42.9726	-52.3091	-53.7792	-57.4165	-55.9175	-56.1953
4.25	-44.8657	-51.0082	-52.8227	-59.9530	-58.2471	-59.1835
4.50	-44.5016	-50.1309	-56.6577	-59.3427	-57.6522	-58.0678
4.75	-46.8478	-50.5529	-58.7323	-59.8075	-57.6833	-55.6654
5.00	-45.1920	-51.5287	-56.4957	-58.0405	-60.7089	-57.8303
5.25	-43.2449	-51.7973	-55.8264	-60.2026	-57.7749	-58.2275
5.50	-44.6629	-49.8225	-57.6836	-58.9612	-57.6731	-58.2231
5.75	-44.5754	-49.6954	-58.7800	-60.3207	-57.7778	-59.1694
6.00	-47.9548	-47.7711	-60.1511	-60.6702	-57.2283	-60.1573
6.25	-47.9003	-48.6007	-61.7519	-60.6639	-57.1479	-59.1589
6.50	-43.0051	-45.2937	-57.3179	-58.2053	-51.1325	-57.6971
6.75	-41.8848	-44.2497	-59.7268	-58.8490	-50.5226	-59.3586
7.00	-38.6034	-43.5492	-58.4256	-56.9380	-48.2957	-57.9066
7.25	-39.2712	-38.6461	-56.3105	-57.8703	-45.4638	-57.8538
7.50	-37.9051	-41.3696	-57.9242	-58.2407	-47.2294	-57.0287
7.75	-31.7701	-37.6828	-55.6661	-58.0913	-44.0778	-50.8765
8.00	-31.0709	-35.9100	-58.1599	-57.0784	-42.7691	-50.1048
8.25	-33.7483	-37.1902	-59.3160	-58.1970	-45.1063	-49.0815
8.50	-36.9592	-41.7303	-54.8978	-56.7641	-49.9122	-49.9588
8.75	-37.5341	-44.1467	-54.3632	-56.0056	-53.1995	-50.8831
9.00	-41.2670	-47.3760	-56.8305	-60.2061	-55.8120	-54.6669
9.25	-42.3598	-44.5862	-58.8648	-58.2793	-55.1517	-56.0540
9.50	-40.9965	-41.3839	-61.1048	-59.8166	-55.1987	-56.7672
9.75	-38.4912	-40.9020	-61.3196	-58.5170	-53.1585	-51.0751
10.00	-33.4503	-32.7670	-58.3611	-54.1328	-46.8394	-51.2728
10.25	-32.1017	-33.7119	-60.5995	-54.9286	-47.1906	-56.5359
10.50	-29.6844	-34.2554	-58.9093	-54.1826	-48.9466	-54.3392
10.75	-30.1341	-35.5228	-55.2803	-57.9935	-50.8814	-53.4805
11.00	-31.8744	-35.6075	-55.5417	-57.6659	-50.4403	-53.9771
11.25	-29.2189	-33.6502	-55.4018	-55.0573	-49.6220	-52.5571
11.50	-30.1398	-32.5398	-55.3563	-53.0856	-49.7134	-55.9456
11.75	-30.3748	-35.6756	-56.8718	-56.0314	-53.1560	-57.0690
12.00	-30.2968	-31.8332	-53.6903	-54.5990	-51.4278	-59.2226
12.25	-29.3586	-27.2338	-54.7070	-50.4514	-49.1196	-60.3689
12.50	-26.8140	-22.9838	-52.5535	-46.7438	-45.4997	-59.1032
12.75	-28.5482	-24.5166	-54.1236	-48.4938	-49.7411	-59.8692
13.00	-28.9051	-26.0126	-54.1250	-50.2353	-53.2531	-59.0311
13.25	-34.3843	-31.8524	-56.5874	-52.4357	-56.2806	-60.8058
13.50	-35.2646	-32.9414	-58.7347	-50.8389	-54.2735	-61.0511

FREQ(HZ)	ROLL	PITCH	YAW	LONG	VERT	LAT
13.75	-32.2660	-27.8035	-54.0113	-46.6405	-50.4475	-61.6609
14.00	-31.6483	-25.1007	-52.9695	-45.0057	-49.9925	-61.0274
14.25	-33.2595	-26.3196	-54.1379	-47.4868	-52.3200	-61.1594
14.50	-33.2256	-28.3400	-56.5585	-49.9864	-54.1432	-59.5799
14.75	-37.0105	-28.8263	-58.3003	-50.8274	-53.6797	-62.5463
15.00	-36.1170	-35.8904	-61.0305	-52.6605	-60.8745	-61.4112
15.25	-37.1991	-36.1438	-60.8396	-51.9862	-56.0941	-60.2102
15.50	-37.4838	-36.1502	-59.7176	-51.7541	-57.7850	-60.4123
15.75	-40.6914	-34.7356	-59.3046	-53.0077	-57.2560	-59.9432
16.00	-40.7065	-36.8950	-56.8405	-53.5652	-56.1191	-60.4388
16.25	-43.4191	-39.2531	-59.2894	-56.7547	-57.0704	-61.7559
16.50	-43.6335	-42.7189	-60.2430	-57.0180	-59.2790	-63.0193
16.75	-42.2727	-38.5728	-58.6491	-56.8824	-58.4632	-60.7882
17.00	-40.2534	-40.9851	-59.3660	-58.0117	-60.1015	-61.4877
17.25	-37.7798	-40.0998	-58.7234	-56.3815	-57.6997	-61.0568
17.50	-37.5126	-39.3109	-58.0305	-58.1436	-58:3185	-63.7830
17.75	-39.1984	-41.9850	-60.2411	-57.8010	-61.5562	-62.3628
18.00	-39.2531	-44.5388	-59.3331	-58.8187	-59.7355	-62.5913
18.25	-36.6574	-44.7559	-54.3661	-57.3937	-58.8310	-57.9302
18.50	-32.6197	-40.9758	-53.7123	-55.1928	-56.9514	-58.2952
18.75	-32.6839	-41.6721	-53.7113	-57.0781	-60.0467	-58.3163
19.00	-36.5312	-45.7228	-53.8019	-59.9827	-64.2085	-61.1347
19.25	-35.9069	-47.0362	-54.0263	-62.3567	-61.7882	-59.5797
19.50	-38.5540	-51.1856	-53.9376	-63.1890	-64.0229	-59.9794
19.75	-39.1212	-51.1965	-53.6822	-62.9081	-65.4346	-60.9091
20.00	-35.3219	-50.9660	-56.4418	-62.1691	-63.7134	-59.6363
20.25	-36.9918	-51.6108	-54.1079	-62.5628	-63.9911	-61.5214
20.50	-40.5704	-52.7836	-57.0995	-63.9912	-64.1353	-61.8932
20.75	-38.2004	-52.7385	-50.7829	-64.8055	-65.3100	-61.2782
21.00	-40.9441	-51.7122	-53.6132	-63.1147	-64.1399	-61.3246
21.25	-39.8950	-53.5745	-51.9551	-63.3956	-61.1939	-61.0541
21.50	-38.0413	-51.8090	-52.8765	-60.3437	-61.2861	-59.2508
21.75	-38.7717	-54.9379	-56.1077	-59.3094	-59.0349	-59.3176
22.00	-39.7703	-54.3686	-55.2792	-63.2344	-63.1421	-62.2176
22.25	-43.1530	-53.6410	-53.5510	-64.1366	-63.9010	-63.6656
22.50	-42.8571	-54.7910	-56.1075	-63.1593	-64.0201	-62.2553
22.75	-41.5439	-56.2965	-56.3293	-64.7568	-66.9637	-63.9704
23.00	-40.7488	-57.9226	-57.0618	-64.4872	-63.4124	-62.5261
23.25	-42.4682	-54.5856	-58.9194	-65.0373	-66.8522	-65.7206
23.50	-43.6545	-56.2600	-61.1761	-66.0042	-68.3059	-66.6226
23.75	-43.3388	-59.2110	-60.4666	-65.7836	-66.4740	-64.0516
24.00	-46.1376	-56.9458	-60.4658	-66.9000	-67.0873	-66.1120
24.25	-48.9115	-56.7558	-62.6264	-65.8513	-66.4951	-68.5669
24.50	-47.1559	-57.3887	-61.7880	-65.0019	-64.8295	-64.9181
24.75	-47.4043	-57.0421	-61.0967	-64.1137	-64.4161	-63.7513
25.00	-48.3605	-58.5697	-62.2209	-67.1746	-66.2733	-67.3100
25.25	-49.1814	-59.2570	-62.4842	-66.5396	-66.6904	-66.4942
25.50	-49.7727	-58.1538	-60.9895	-67.9297	-65.7673	-65.3541
25.75	-51.4546	-58.3048	-64.7968	-68.2684	-69.0442	-67.3896
26.00	-48.6170	-59.0424	-62.0467	-64.8179	-65.3170	-64.6886
26.25	-49.7328	-59.1065	-62.5065	-65.5400	-64.3936	-65.2648
26.50	-49.8149	-58.5414	-63.0807	-67.1364	-66.3312	-66.0648
26.75	-48.6844	-57.8849	-64.1525	-68.3190	-69.1965	-67.7249
27.00	-48.5715	-58.3542	-64.9372	-66.0981	-67.0128	-67.0579

PSD LEVELS (DB)

FREQ(HZ)	ROLL	PITCH	YAW	LONG	VERT	LAT
27.25	-48.8904	-60.7774	-64.6064	-66.7565	-66.3212	-66.0981
27.50	-48.7567	-58.5140	-65.5674	-68.2001	-67.8819	-67.9919
27.75	-45.5269	-59.9914	-64.7770	-66.6783	-67.4007	-66.0710
28.00	-45.0649	-61.4549	-64.4134	-67.2284	-67.1453	-66.3267
28.25	-44.3666	-61.8383	-62.7597	-66.8092	-65.2522	-64.5029
28.50	-44.6969	-59.3493	-66.0285	-68.5383	-68.7164	-66.2743
28.75	-43.1152	-59.5386	-64.7828	-67.2016	-64.3066	-68.1394
29.00	-39.2889	-56.2382	-66.7024	-65.2194	-62.0418	-66.8401
29.25	-41.1996	-57.1751	-65.0454	-66.0494	-65.1305	-66.3909
29.50	-45.7457	-61.3613	-64.9475	-67.1300	-68.0757	-66.6703
29.75	-47.9855	-61.0034	-64.6958	-67.1502	-67.4932	-67.5722
30.00	-47.2372	-58.9014	-63.6993	-65.2930	-66.5262	-66.1475
30.25	-45.5217	-61.3449	-64.3471	-64.6371	-65.7523	-64.4379
30.50	-47.7786	-58.3773	-63.1920	-63.8517	-63.4437	-64.7278
30.75	-46.7486	-61.6398	-64.7428	-67.4260	-65.6369	-67.0469
31.00	-47.0129	-59.1248	-63.0461	-64.9225	-63.1093	-64.4070
31.25	-44.6497	-58.5987	-64.3733	-63.8347	-64.6044	-65.1910
31.50	-46.5221	-63.2111	-63.5192	-68.2183	-66.0899	-68.7306
31.75	-48.9084	-63.4027	-65.5058	-67.0556	-67.6304	-68.2720
32.00	-44.1786	-61.1839	-68.2881	-66.7513	-67.2930	-66.6784
32.25	-44.1159	-62.5139	-67.3836	-68.5487	-66.8219	-67.3321
32.50	-46.1151	-62.8145	-64.5134	-67.6012	-67.0355	-67.5009
32.75	-45.5774	-62.6741	-64.9826	-67.7825	-70.7328	-68.1976
33.00	-43.3638	-62.3432	-66.7482	-69.5741	-69.9901	-67.6283
33.25	-45.6095	-64.0278	-65.7432	-68.0593	-70.0903	-67.8280
33.50	-45.8266	-62.4872	-66.2198	-69.0443	-70.0080	-70.0394
33.75	-46.5872	-61.3348	-66.1177	-68.7597	-70.1982	-69.2234
34.00	-44.5565	-64.8838	-69.1964	-70.4772	-69.4997	-69.6459
34.25	-47.3761	-66.2084	-69.7234	-70.9327	-68.3449	-70.8379
34.50	-46.7352	-63.5553	-69.6340	-69.2380	-69.1368	-67.5914
34.75	-52.4139	-64.5359	-68.7779	-69.5181	-69.5234	-71.2436
35.00	-55.0743	-63.3907	-69.8342	-70.0202	-70.5237	-70.5238
35.25	-54.6833	-62.7625	-69.7353	-70.4161	-71.4677	-71.6380
35.50	-55.2400	-66.8191	-70.5721	-70.8941	-69.7549	-73.1050
35.75	-54.4122	-65.6704	-70.3078	-71.6775	-70.9314	-73.4510
36.00	-54.8105	-65.1081	-69.2536	-69.5421	-69.1677	-70.9489
36.25	-53.1294	-65.1203	-71.6678	-71.1389	-70.4291	-70.6093
36.50	-51.8952	-66.2635	-68.2019	-69.4809	-69.0049	-68.5894
36.75	-50.0329	-65.1826	-67.7549	-70.3744	-69.7571	-68.8356
37.00	-53.6458	-65.1287	-68.9962	-70.5325	-70.2808	-69.5603
37.25	-53.8759	-63.8137	-69.0961	-69.8488	-70.6923	-70.2372
37.50	-51.3045	-64.5729	-69.2417	-70.8474	-69.7610	-69.9775
37.75	-51.5060	-66.2966	-68.6949	-68.7681	-68.0482	-68.9250
38.00	-53.4536	-66.8979	-71.4782	-71.9435	-70.6634	-72.1737
38.25	-53.7970	-66.5710	-68.0120	-70.6449	-70.6243	-69.6139
38.50	-54.0456	-67.2227	-69.6829	-72.4383	-71.2673	-71.3028
38.75	-54.3708	-65.9762	-69.2598	-71.3416	-71.2313	-71.4984
39.00	-54.3495	-65.0584	-70.8732	-71.9331	-72.5918	-73.3321
39.25	-53.9370	-67.8747	-69.0564	-71.7183	-71.8330	-72.0449
39.50	-56.0606	-65.3799	-69.3932	-71.5472	-72.9121	-72.2241
39.75	-53.2189	-65.5508	-68.3261	-69.0442	-70.3715	-68.7685
40.00	-51.5997	-64.0616	-65.7068	-67.1520	-67.2090	-67.0379

V I B R A T I O N   A N A L Y S I S   S U M M A R Y

FILE07

TEST 23A,B MSG 191-211 COACH 60 MPH BAL

FILE 7 TEST 23A MSG 194-199 REC 30-86

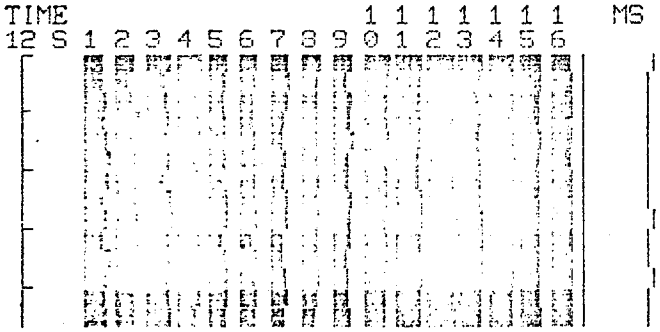
	LONG G'S	LAT G'S	VERT G'S
STANDARD DEVIATION	0.010	0.012	0.014
95 PER CENT LEVEL	0.019	0.024	0.028
99 PER CENT LEVEL	0.027	0.031	0.038

	LONG	LAT	VERT
MINIMUM EXPOSURE TIME (REDUCED COMFORT)	HOURS 24.000	HOURS 14.456	HOURS 11.411
CENTER FREQUENCY BAND	HZ 1.000	HZ 1.600	HZ 8.000
ALTERNATE METHOD EXPOSURE TIME (REDUCED COMFORT)	HOURS 24.000	HOURS 6.562	HOURS 6.696

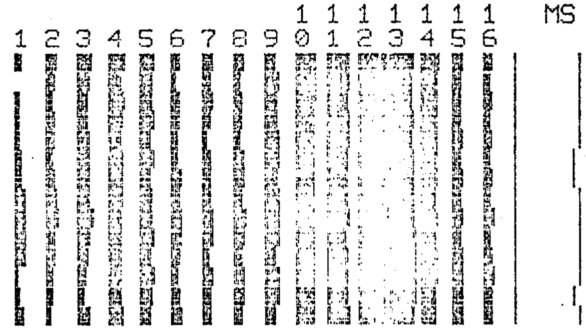
FILE07[illegible] TEST 23A,B MSG 191-211 COACH 60 MPH BAL
FILE 7 TEST 23A MSG 194-199 REC 30-86

CEPSTRUM PLOT OF POWER SPECTRA 1/3 OCTAVE BANDS

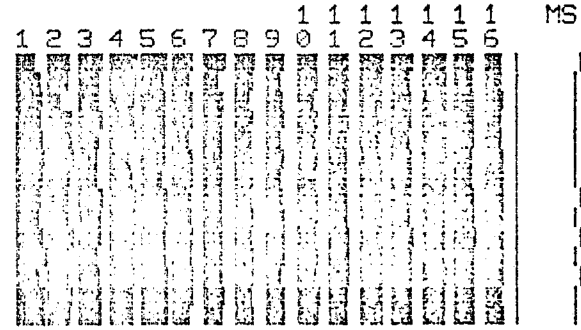
ROLL
RAD/SEC/SEC



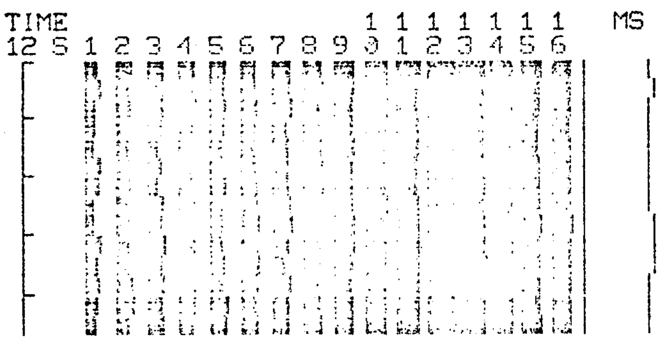
PITCH
RAD/SEC/SEC



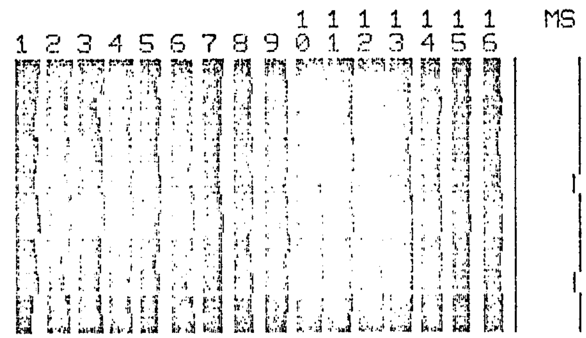
YAW
RAD/SEC/SEC



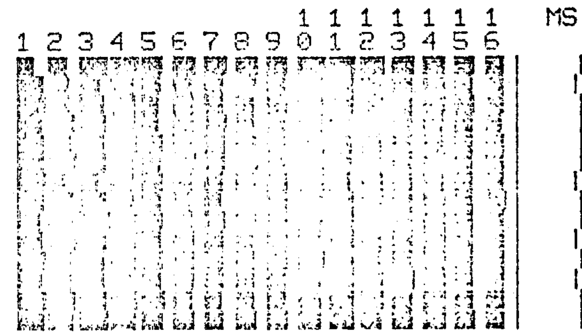
LONG
G'S



VERT
G'S

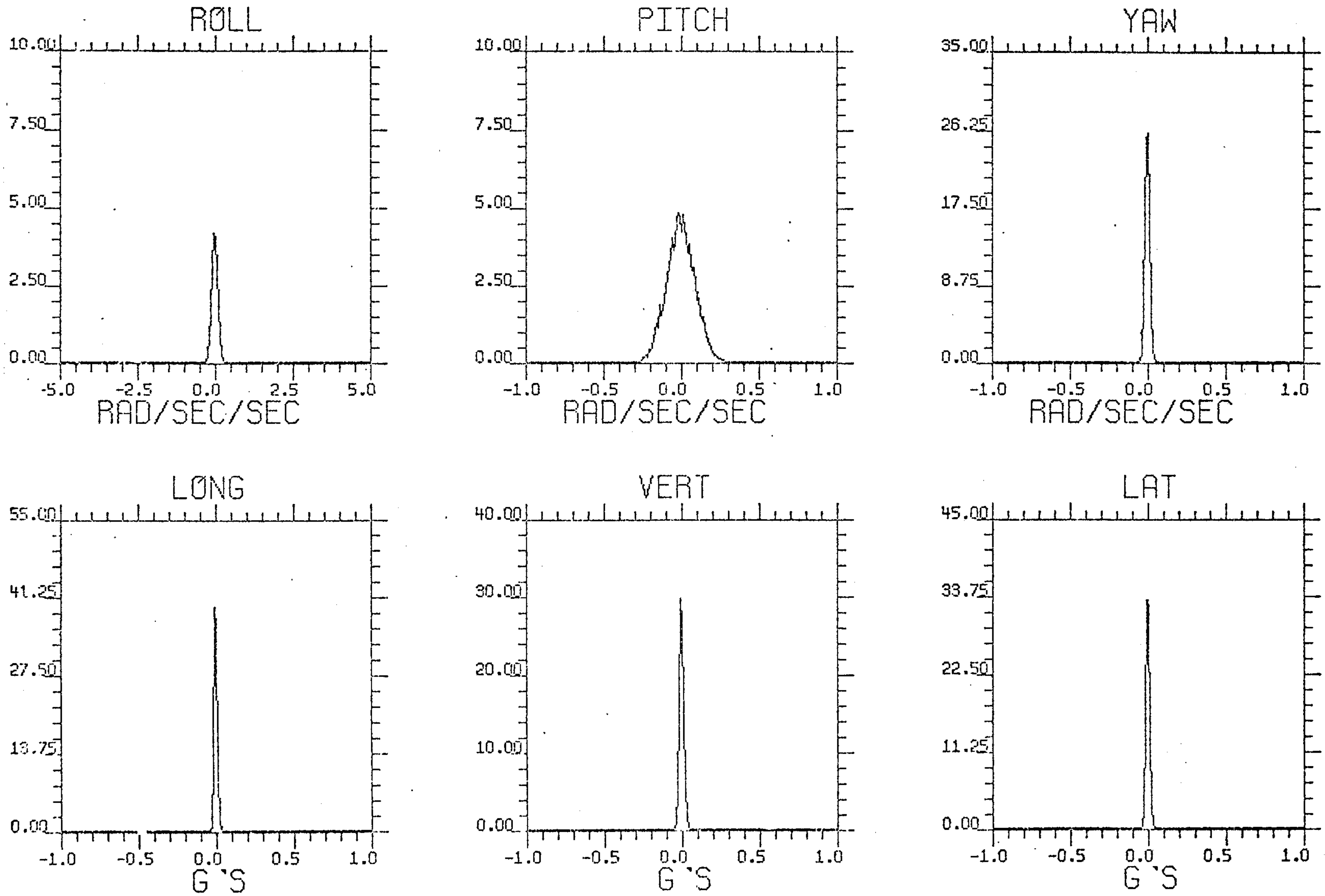


LAT
G'S



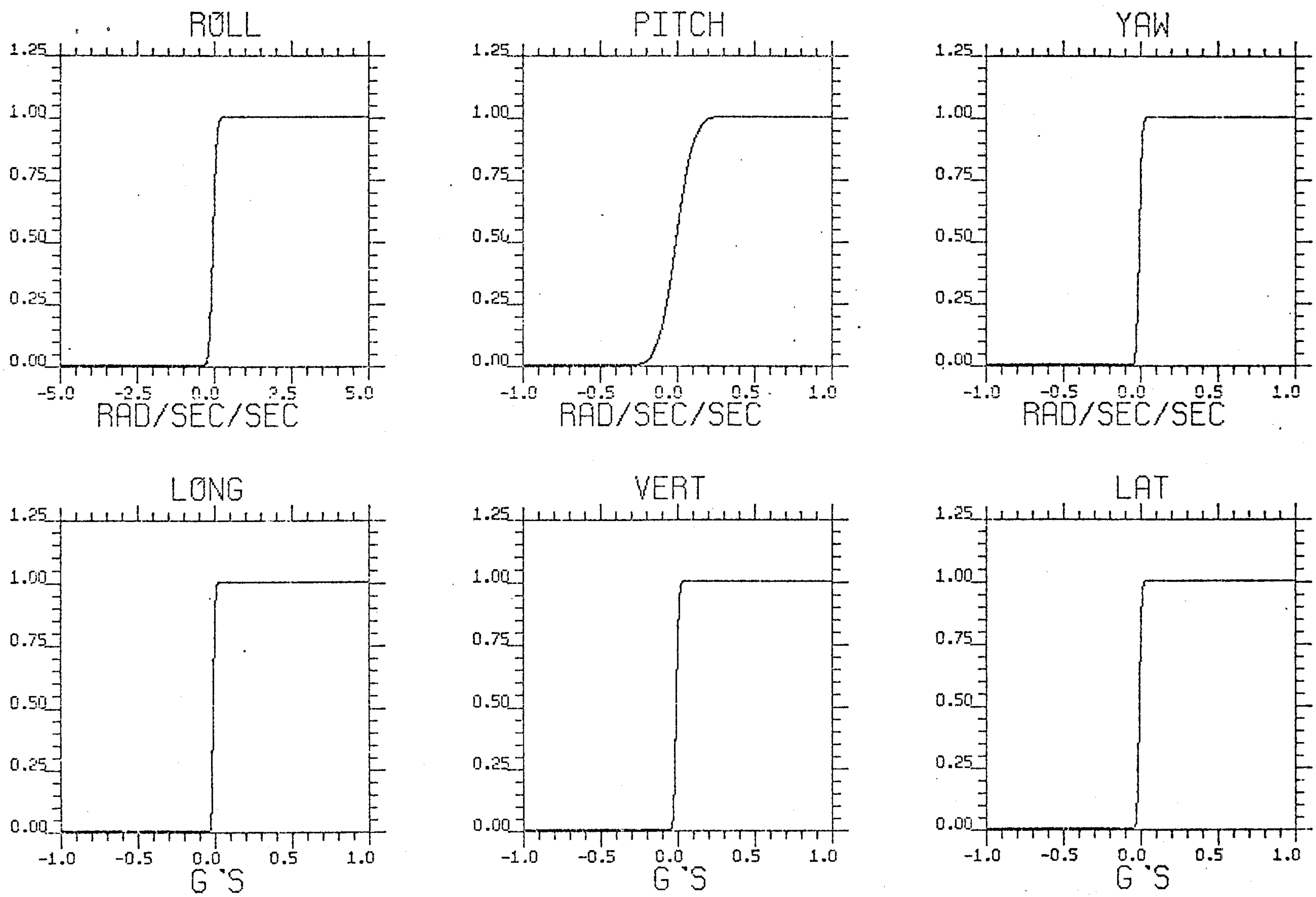
PROBABILITY DENSITY ESTIMATE

TEST 23A,B MSG 191-211 COACH 60 MPH BAL
FILE 7 TEST 23A MSG 194-199 REC 30-88

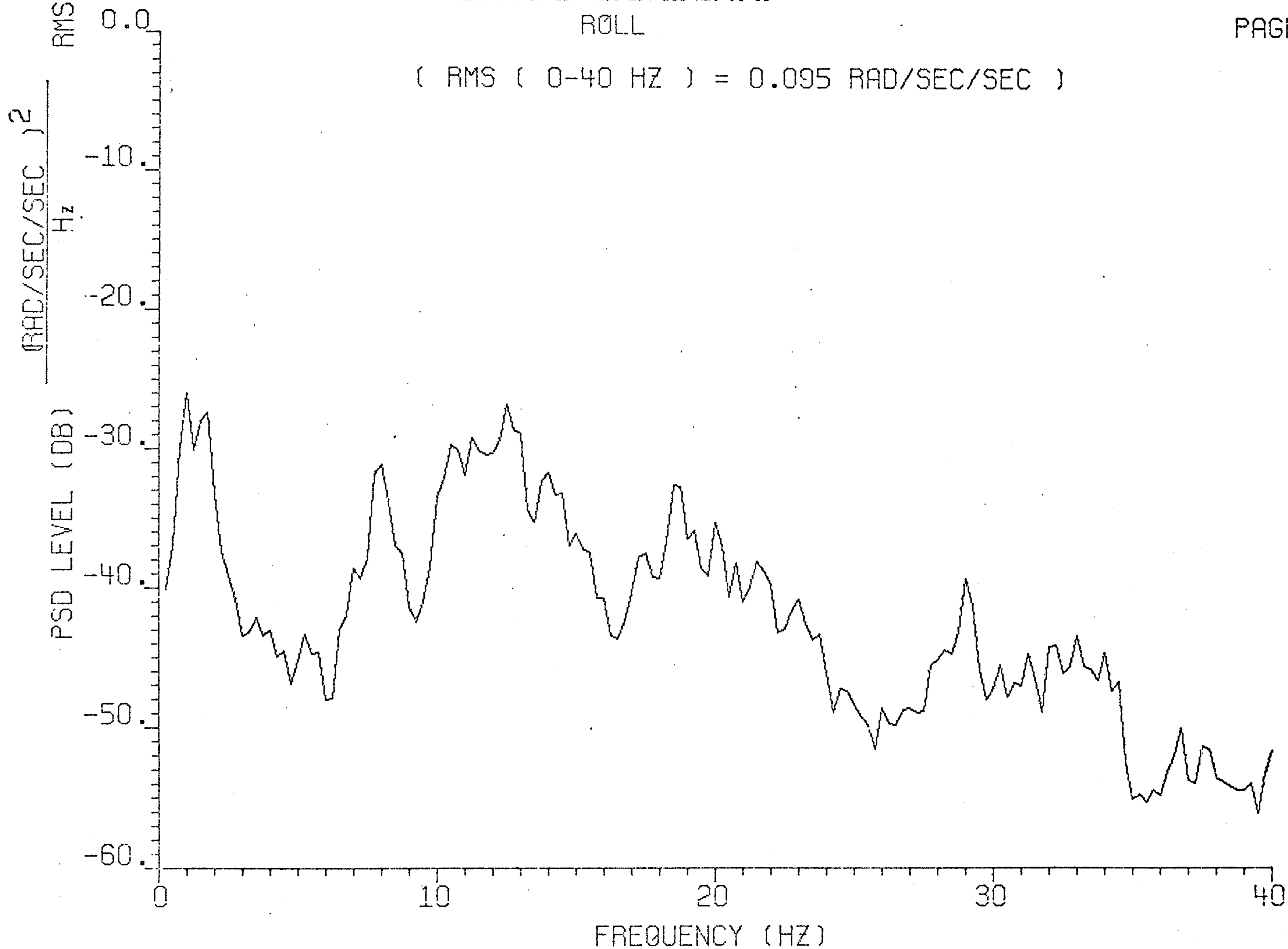


DISTRIBUTION FUNCTION ESTIMATE

TEST 23A.B MSG 191-211 COACH 60 MPH BAL
FILE 7 TEST 23A MSG 194-199 REC 30-86



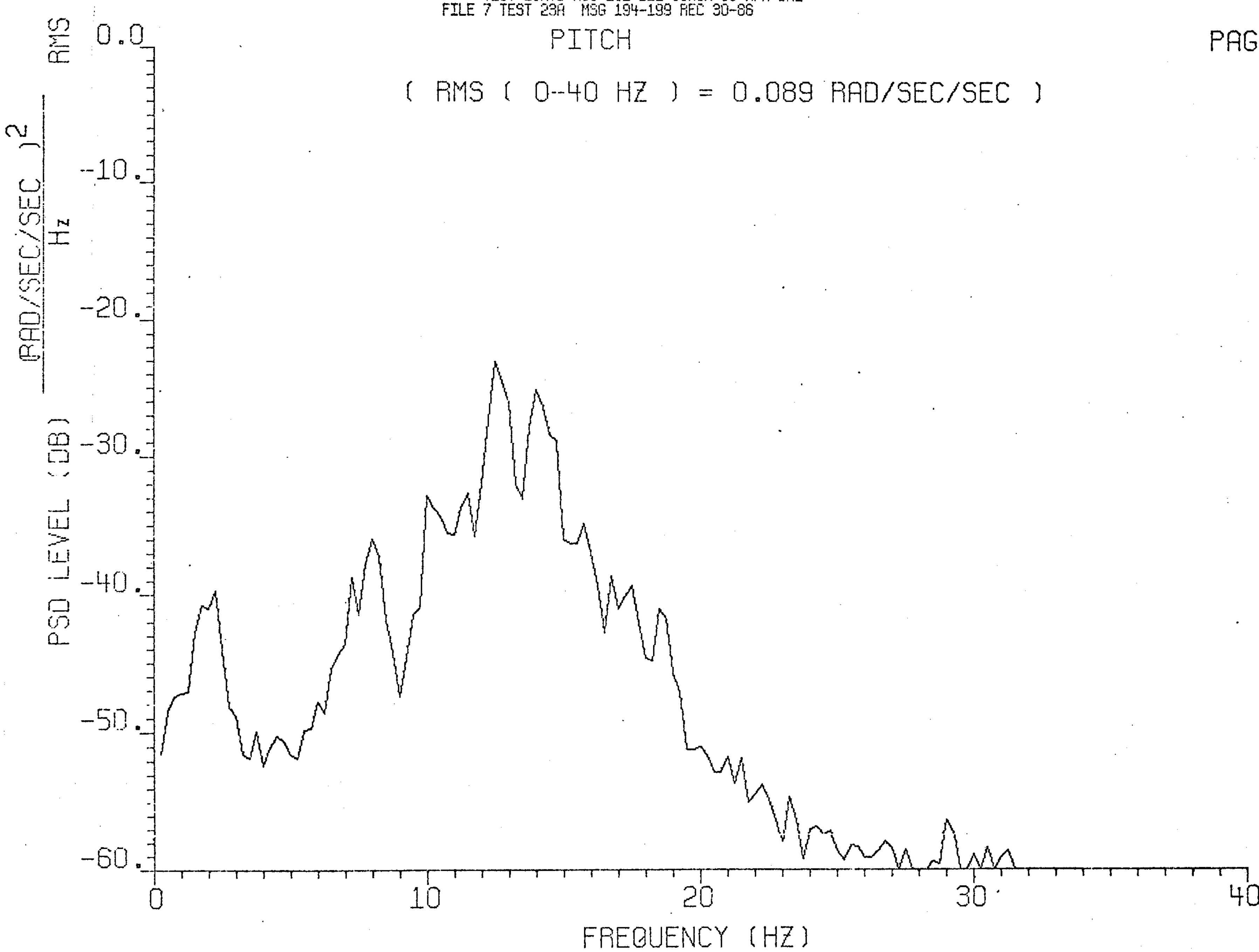
TEST 23A,B MSG 191-211 COACH 60 MPH BAL
FILE 7 TEST 23A MSG 194-199 REC 30-86

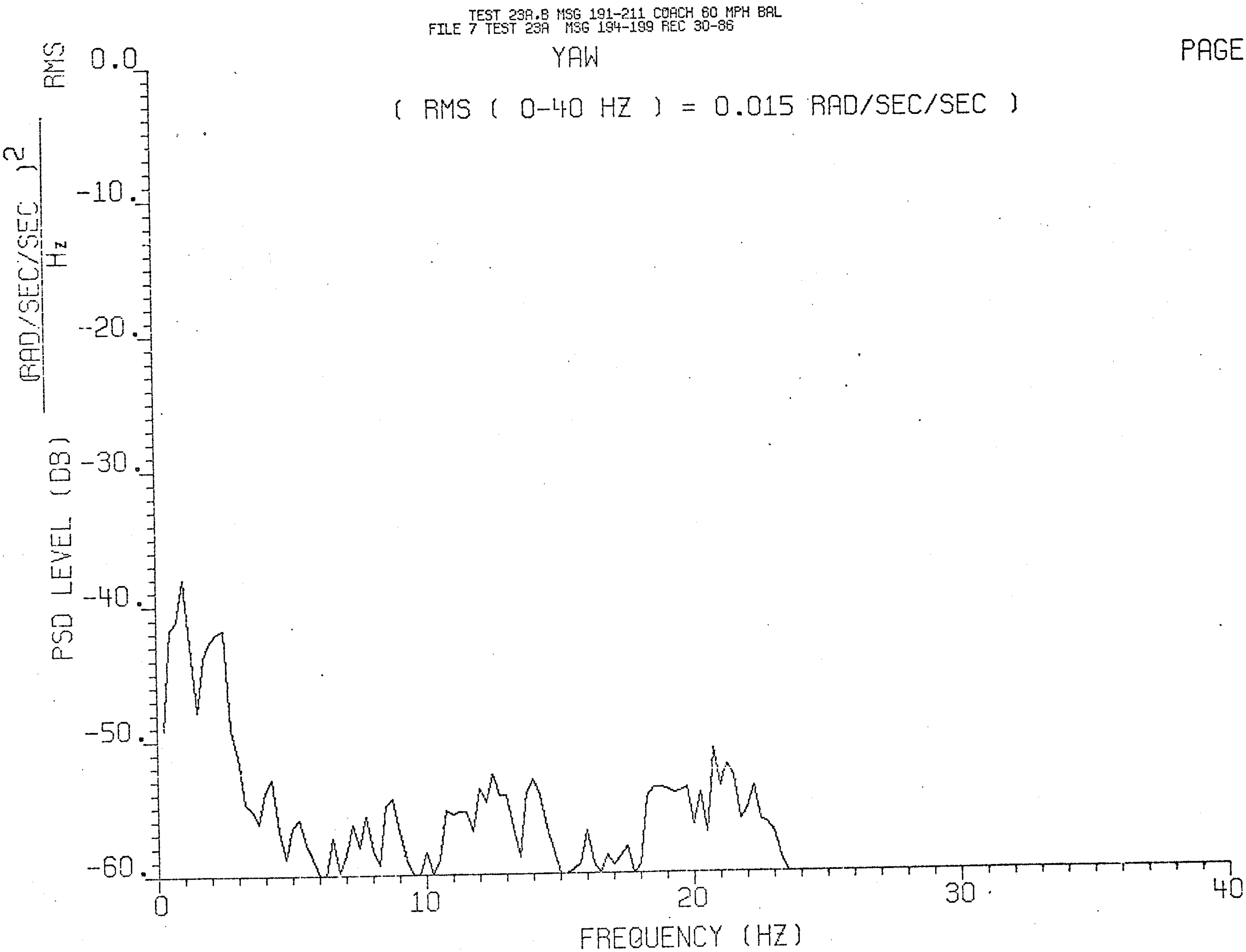


TEST 23A.B MSG 191-211 COACH 60 MPH BAL
FILE 7 TEST 23A MSG 194-199 REC 30-86

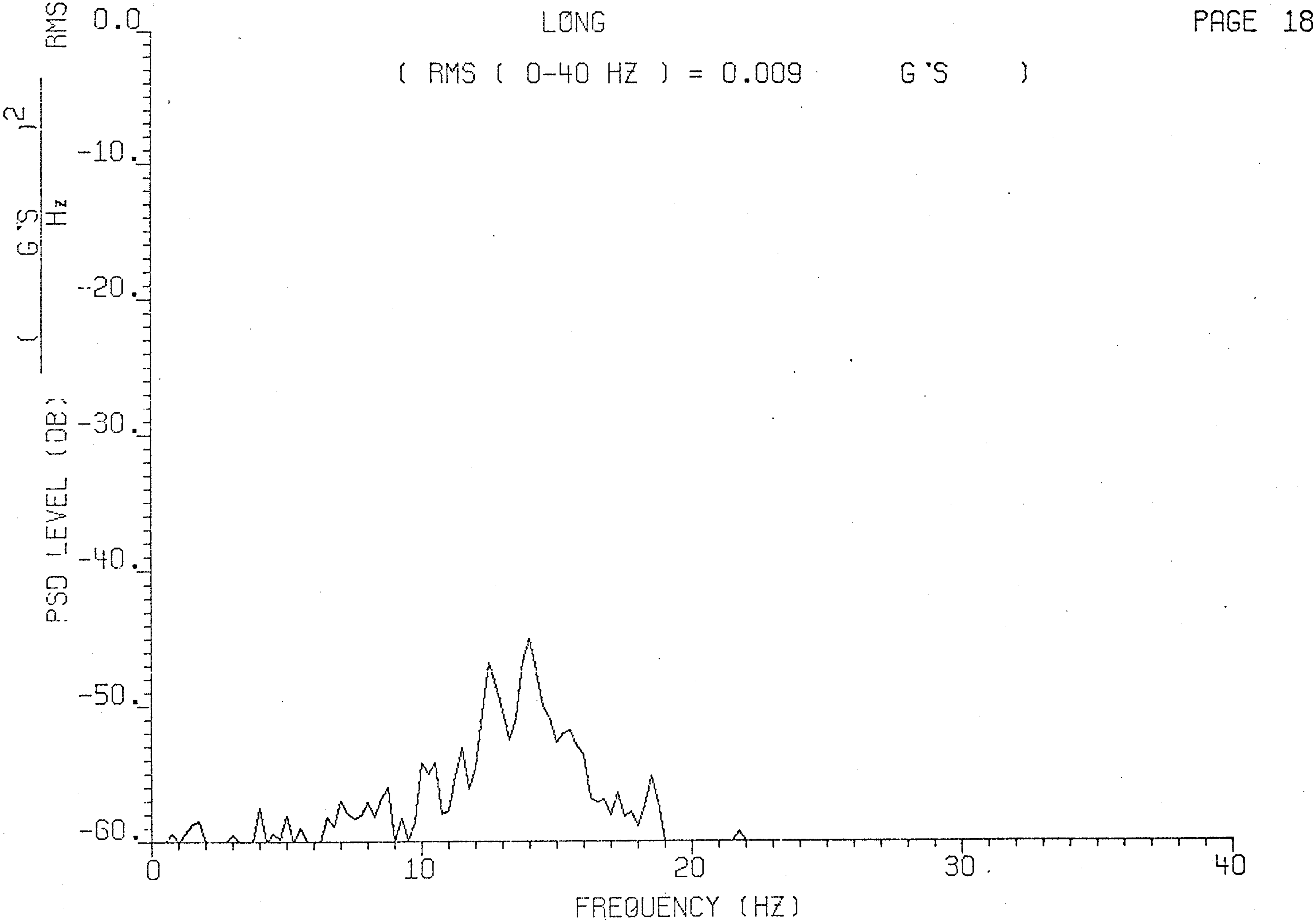
PITCH

(RMS (0-40 HZ) = 0.089 RAD/SEC/SEC)

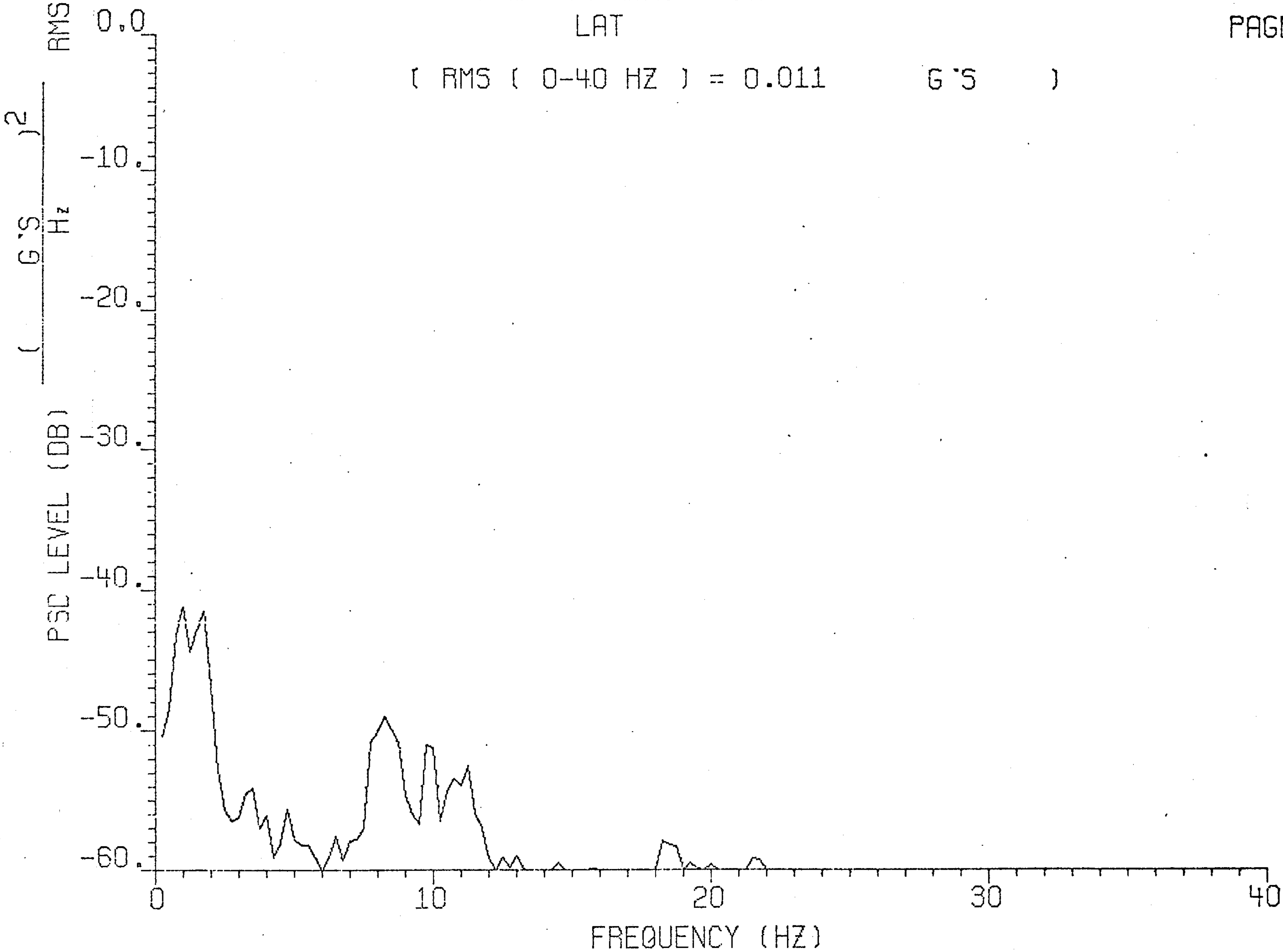



TEST 23A.B MSG 191-211 COACH 60 MPH BAL
FILE 7 TEST 23A MSG 194-199 REC 30-86
YAW
(RMS (0-40 HZ) = 0.015 RAD/SEC/SEC)
PSD LEVEL (DB) (RAD/SEC/SEC)² / Hz RMS
0.0
-10.
-20.
-30.
-40.
-50.
-60.
0
10
20
30
40
FREQUENCY (HZ)

TEST 23A,B MSG 191-211 COACH 60 MPH BAL
FILE 7 TEST 23A MSG 194-199 REC 30-86



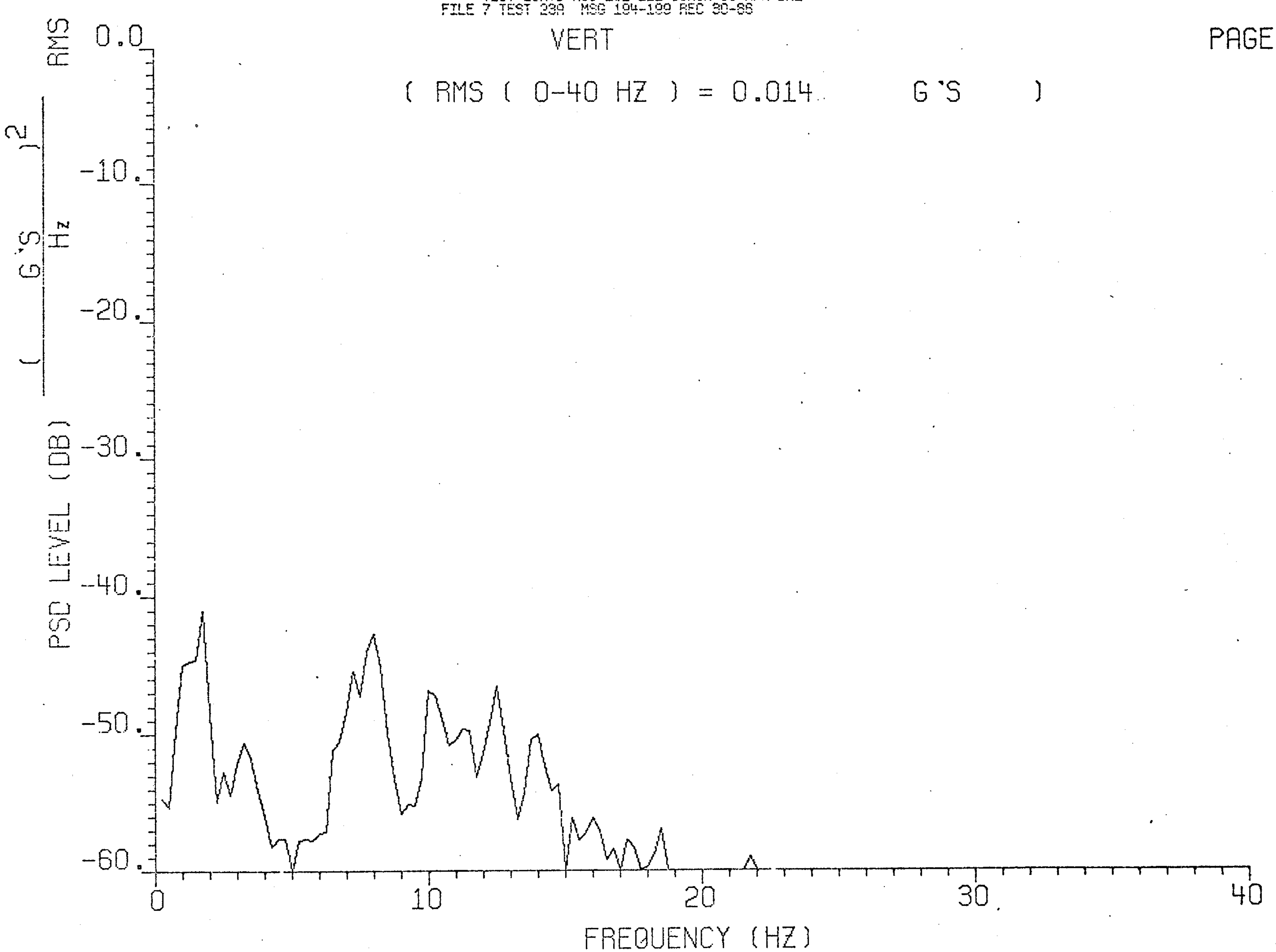
TEST 23A,B MSG 191-211 COACH 60 MPH BAL
FILE 7 TEST 23A MSG 194-199 REC 30-86



TEST 23A.B MSG 191-211 COACH 60 MPH BAL
FILE 7 TEST 23A MSG 194-199 REC 30-88

VERT

(RMS (0-40 HZ) = 0.014 G'S)

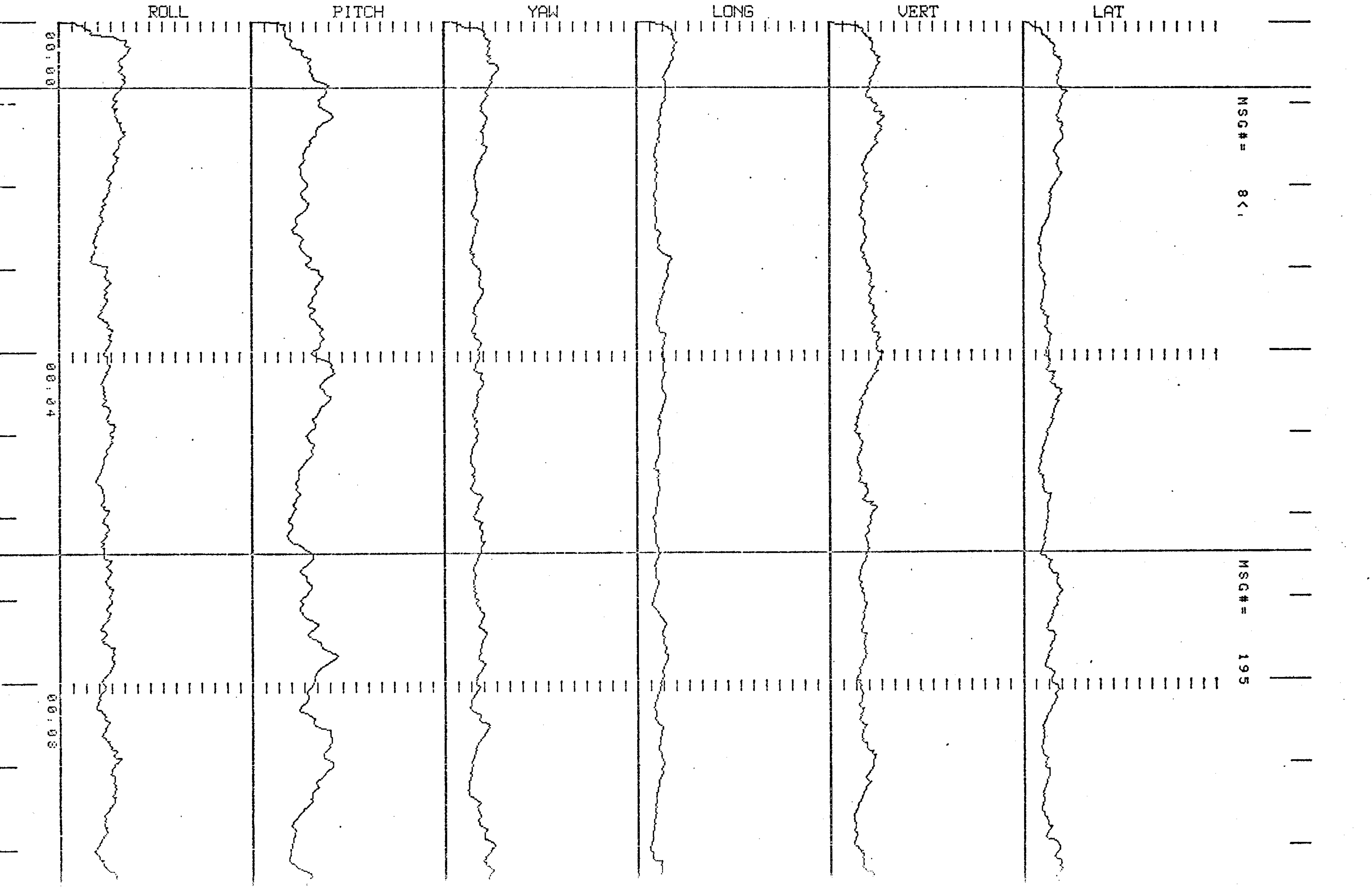


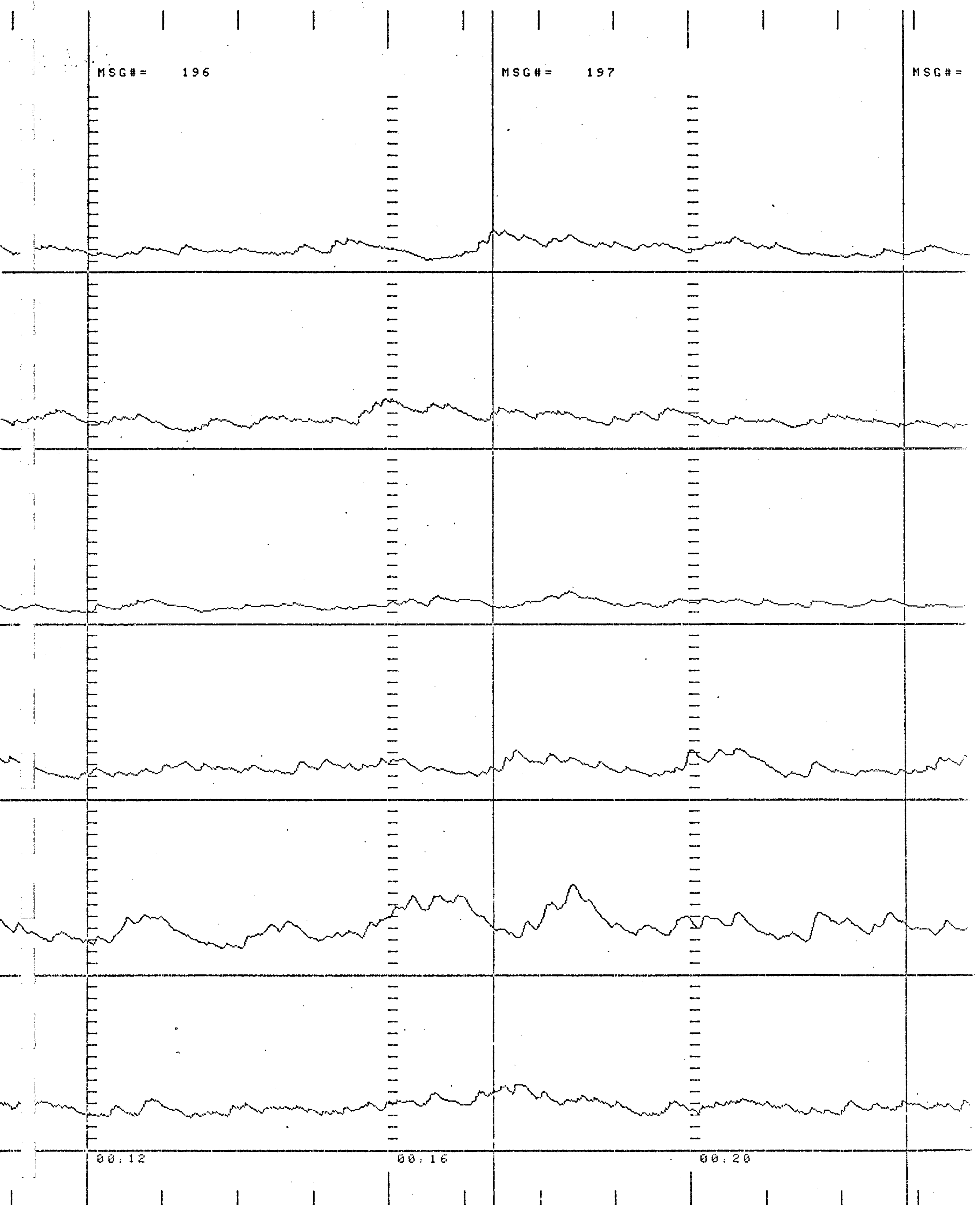
CHANNEL DEFINITION

CHANNEL NUMBER	DESCRIPTION				ENGINEERING UNITS PER COUNT	CHANNEL RANGE	UNITS PER MINOR DIVISION
1 - 1	ROLL	(RAD/SEC/SEC)	RMS	2 RECORDS/SEC	0.0024420	0.38	0.025
2 - 2	PITCH	(RAD/SEC/SEC)	RMS	2 RECORDS/SEC	0.0004884	0.30	0.020
3 - 3	YAW	(RAD/SEC/SEC)	RMS	2 RECORDS/SEC	0.0004884	0.07	0.005
4 - 4	LONG	(G'S)	RMS	2 RECORDS/SEC	0.0004884	0.07	0.005
5 - 5	VERT	(G'S)	RMS	2 RECORDS/SEC	0.0004884	0.07	0.005
6 - 6	LAT	(G'S)	RMS	2 RECORDS/SEC	0.0004884	0.07	0.005

FI'E 7 TEST 23A MSG 194-199 REC 30-86

I-----CH 1---------I------CH 2-------I------CH 3--------I--------CH 4--------I--------CH 5--------I--------CH 6-------I





MSG#= 196
MSG#= 197
MSG#=
00:12
00:16
00:20

APPENDIX C

DIGITAL ALGORITHMS

APPENDIX C
DIGITAL ALGORITHMS

The block diagram for processing the ride quality data is defined in terms of transfer function characteristics of continuous systems. Since the processing is accomplished by a digital computer, a numerical algorithm is required instead of this transfer function. The concept of a digital transfer function and the incorporation of an appropriate integration scheme will be used to generate a numerical algorithm for transfer functions given in the block diagram.

The techniques described in this appendix are based on an article which appeared in the periodical Simulation, August 1968. The article was entitled "Techniques for the Design of Linear Digital Simulations." The authors are R. E. Gagne and D. C. Baxter.

The concept of this technique is related to the Z-transfer method used to treat many problems associated with sampled controlled systems. The digital system input is a sequence of values (R_N). This sequence can be represented by the pseudotime signal

$$(R_N) \xrightarrow[\text{By}]{\text{Represented}} \sum_{N=0}^{\infty} R_N \, \delta(t-Nh) = R(t)$$

The Laplace transform of R(t) is given by

$$L[R(t)] = \sum_{N=0}^{\infty} R_N \, e^{-sNh}$$

By introducing the mapping $Z = e^{sh}$, this expression becomes

$$\sum_{N=0}^{\infty} R_N e^{-sNh} = \sum_{N=0}^{\infty} R_N Z^{-N}$$

The expression on the right-hand side of the equation represents the Z-transform of R(t). Note that mapping $Z = e^{sh}$ maps the negative real half plane of the s-domain into the unit circle. Stability of a transfer function in the Z-domain implies that all the poles lie on or inside the unit circle poles.

For the continuous system in the s-domain, multiplication by s is equivalent to differentiation in the time domain. Multiplication by Z of the digital function K(Z), is equivalent in the time domain of going from

$$R(t) = \sum_{N=0}^{\infty} R_N \delta(t-Nh)$$

to the function

$$R'(t) = \sum_{N=0}^{\infty} R_{N+1} \delta(t-Nh)$$

as can be seen by

$$R(t) \xrightarrow{\text{Z Transform}} \sum_{N=0}^{\infty} R_N Z^{-N}$$

$$Z \sum_{N=0}^{\infty} R_N Z^{-N} = \sum_{N=0}^{\infty} R_N Z^{-N+1}$$

$$\sum_{N=0}^{\infty} R_N Z^{-N+1} \longrightarrow R'(t) = \sum_{N=0}^{\infty} R_N \delta(t-Nh+h) \quad \text{for } t > 0$$

which for M = +N-1

$$R'(t) = \sum_{M=0}^{\infty} R_{M+1}\ \delta(t-Mh) \quad \text{for } t > 0$$

A shorthand notation for use in going from the Z-domain to time domain is given by

$$\bar{y}(z) \longrightarrow y_i$$

$$Z\ \bar{y}(z) \longrightarrow y_{i+1}$$

The concept of a digital transfer function becomes especially useful when an integration procedure is defined and used to go directly from the continuous transfer function to the numerical algorithm. The trapezoidal rule for integration will be used. It is given by

$$y_{i+1} = y_i + \frac{\Delta t}{2}\ (x_{i+1} + x_i)$$

For integration (i.e., 1/s), the digital transfer function becomes

$$y_{i+1} - y_i = \frac{\Delta T}{2}\ (x_{i+1} + x_i)$$

$$\bar{y}_i(Z-1) = \frac{\Delta T}{2}\ x_i\ (Z+1)$$

$$\frac{\bar{y}_i}{\bar{x}_i} = \frac{\Delta T}{2}\ \frac{Z+1}{Z-1}$$

or in outline form

$$\frac{1}{S} \longrightarrow \frac{\Delta T}{2}\ \frac{Z+1}{Z-1}$$

or $$S \longrightarrow \frac{2}{\Delta T}\ \frac{Z-1}{Z+1}$$

Si ce these terms can be handled algebraically, the numerical algorithm can thus be handled by substitution of

$\frac{\Delta 2}{T}\frac{Z-1}{Z+1}$ for s in the transfer function of the continuous system.

Ap lying the rules for going from the Z-domain to the t-domain tc a first-order system, we have

$$\frac{\bar{y}(s)}{\bar{x}(s)} = \frac{1}{\tau_1 s+1}$$

which in replacing s by $\frac{2}{\Delta T}\frac{Z-1}{Z+1}$ yields

$$\frac{\bar{y}(Z)}{\bar{x}(Z)} = \frac{1}{\frac{2}{\Delta T}\frac{Z-1}{Z+1}+1}$$

$$= \frac{Z+1}{\frac{2}{p}(Z-1) + (Z+1)}$$

$$= \frac{p}{2}\frac{Z+1}{(Z-1) + \frac{p}{2}(Z+1)}$$

$$= \frac{p}{2}\frac{Z+1}{(1+\frac{p}{2})Z - (1-\frac{p}{2})}$$

where $p = \frac{\Delta T}{\tau_1}$

This expression can be written

$$(1+\tfrac{p}{2})Z\bar{y}(Z) - \bar{y}(Z)(1-\tfrac{p}{2}) = \tfrac{p}{2}(Z+1)\bar{x}(Z)$$

which in the time domain implies

$$(1+\frac{p}{2})y_{i+1} - (1-\frac{p}{2})y_i = \frac{p}{2}(x_{i+1} + x_i)$$

or

$$y_{i+1} = \frac{(1-\frac{p}{2})}{(1+\frac{p}{2})} y_i + \frac{p}{2}\frac{1}{(1+\frac{p}{2})}(x_{i+1} + x_i)$$

which in the numerical algorithm for the transfer function yields

$$K(S) = \frac{1}{\tau_1 S+1}$$

The algorithm for the block diagram of Figure 10 becomes

$$\bar{x}_{i+1} = a\,\bar{x}_i + b(x_{i+1} + x_i)$$

$$\tilde{x}_{i+1} = x_{i+1} - \bar{x}_{i+1}$$

$$y_{i+1} = \left(\tilde{x}_{i+1}\right)^2$$

$$\bar{y}_{i+1} = c\bar{y}_i + d(y_{i+1} + y_i)$$

$$RMS_{i+1} = \sqrt{\bar{y}_{i+1}}$$

$$\bar{x}_i = \bar{x}_{i+1}$$

$$\bar{y}_i = \bar{y}_{i+1}$$

where

$$a = \left(1 - \frac{h}{2\tau_1}\right) \Big/ \left(1 + \frac{h}{2\tau_1}\right)$$

$$b = \left(\frac{h}{2\tau_1}\right) \Big/ \left(1 + \frac{h}{2\tau_1}\right)$$

$$c = \left(1 - \frac{h}{2\tau_2}\right) \Big/ \left(1 + \frac{h}{2\tau_2}\right)$$

$$d = \left(\frac{h}{2\tau_2}\right) \Big/ \left(1 + \frac{h}{2\tau_2}\right)$$

and

$\bar{x}$ = DC bias term

$\tilde{x}$ = AC portion of x

Note that the transfer function

$$\frac{\tau_1 s}{\tau_1 s+1}$$

has been replaced by

$$\frac{\tau_1 s}{\tau_1 s+1} = 1 - \frac{1}{\tau_1 s+1}$$

Values for the parameters used in Figure 10 may change after initial runs, but should have values similar to those given below

$$\tau_1 = \frac{1}{2\pi f_{min.}} = 0.32 \text{ sec.}$$

$$\tau_2 = 0.50 \text{ sec.}$$

$\Delta T = h = 0.01$ sec. sampling interval and integration time step.

APPENDIX D

PROGRAM REFORM

APPENDIX D
PROGRAM REFORM

1. DESCRIPTION

This program is used when data digitized at 256 Hz is needed for the new ride quality package (VIBES). Data collected in the past was digitized at 256 Hz and stored in 256 sample records. This program throws away every other point, which simulates a 128-Hz digitizing rate and results in a 128-sample record (compatible with VIBES). This program will be used mainly on ride quality data processed before July 1976. A listing of the program is shown in Figure D1. Control cards are listed in Figure D2.

2. INPUT PARAMETERS AND OPERATION

Input to the program is one card on an IS format, as follows:

BREC - beginning record.
EREC - ending record.
ISKP - number of files to skip
- when processing more than one file, add 1 to skip rest of last file processed.

ISHIFT = 0 - data are right justified (ride quality).
$\neq$ 0 - left shift 4 bits
NCHANS - Number of channels (7 in ride quality.

Input Tape - Tape 8 Unit 0 (16)
Output Tape - Tape 9 Unit 1 (17)
Scratch Tape - Tape 10 Unit 0-1 (18)

```
      PROGRAM PEFORM
C     BREC----FIRST RECORD
C     EREC----LAST RECORD
C     ISKP----NUMBER OF FILES TO SKIP, WHEN PROCESSING MORE THAN ONE
C     FILE ADD 1 TO FILES TO SKIP TO SKIP REST OF LAST FILE PROCESSED
      INTEGER ODATA,BREC,EREC,BFILE,ADATA(7,475),DDATA
      COMMON/B1/IHD(39),IDATA(13,256),ODATA(7,128),BREC,EREC,BFILE
      EQUIVALENCE(IDATA(1,1),ADATA(1,1))
      IAP=0
      CALL POPEN(IAP,0,0,0,1,5)
      IFLG=0
      IFILE=1
 600  CONTINUE
      ISTAT=0
      READ(2,100) BREC,EREC,ISKP,ISHIFT,NCHANS
 100  FORMAT(16I5)
      LENGTH=256*NCHANS
      NRECS=1
      IUN=8
      IF(IFLG.EQ.1) ISKP=1
      IF(IFLG.EQ.1) IFLG=0
      IF(BREC.EQ.0) GO TO 99
      IF(ISKP.EQ.0) GO TO 200
      DO 300 I=1,ISKP
 2    FORMAT(39A2)
      DO 400 J=1,10000
      CALL READT(IDATA,LENGTH,8,ISTAT)
      IF(ISTAT.LT.0) GO TO 300
 400  CONTINUE
 300  CONTINUE
 200  CONTINUE
      CALL READT(IHD,39,8,ISTAT)
      IF(ISTAT)90,10,90
 10   IUN=9
      CALL WRITET( IHD,39,9,ISTAT)
      IF(ISTAT)90,15,90
 15   IUN=10
      IF(NCHANS.EQ.7) GO TO 17
      CALL WRITET(IHD,39,10,ISTAT)
      IF(ISTAT)90,17,90
 17   IF(BREC-1)99,22,18
 18   DO 20 I=1,BREC-1
      IUN=8
      CALL READT(IDATA,LENGTH,8,ISTAT)
      IF(ISTAT)90,20,90
 20   CONTINUE
 22   DO 30 I=BREC,EREC
      IUN=8
      CALL READT(IDATA,LENGTH,8,ISTAT)
      IF(ISTAT)90,25,90
 25   DO 3000 N=1,2
      IF(NCHANS.EQ.7.AND.N.EQ.2) GO TO 3000
      IUN=N+8

      DO 28 J=2,256,2
C         PICK UP STATUS WRD MSG CODE FROM ODD SCAN
      IF(NCHANS-7)250,255,250
 250  DDATA=IDATA(1,J-1)
      GO TO 257
 255  DDATA=ADATA(1,J-1)
 257  IF(DDATA)26,27,27
 26   IF(NCHANS-7)260,265,260
 260  IDATA(1,J)=DDATA
      GO TO 27
 265  ADATA(1,J)=DDATA
 27   JSUB=J/2
      IF(NCHANS-7)272,274,272
 272  DDATA=IDATA(1,J)
      GO TO 275
 274  DDATA=ADATA(1,J)
 275  ODATA(1,JSUB)=DDATA
      DO 28 K=2,7
      IF(NCHANS-7)277,278,277
 277  KSUB=K+(N-1)*6
      DDATA=IDATA(KSUB,J)
      GO TO 279
 278  DDATA=ADATA(K,J)
 279  ODATA(K,JSUB)=DDATA
 28   CONTINUE
C         IF ISHIFT NON-ZERO MAKE LEFT SHIFT 4 BITS
      IF(ISHIFT)280,29,280
 280  DO 285 K=2,7
      CALL PSLA(ODATA(K,1),7,ODATA(K,1),7,4,128,0)
      CALL PWAIT
 285  CONTINUE
 29   CALL WRITET(ODATA,896,IUN,ISTAT)
      IF(ISTAT)90,3000,90
 3000 CONTINUE
      NRECS=NRECS+1
 30   CONTINUE
 35   ENDFILE 9
      IF(NCHANS.EQ.7) GO TO 37
      ENDFILE 10
 37   PRINT 1001, IFILE,NRECS,IHD
 1001 FORMAT(' FILE ',I3,',',I5,' RECS, HD: ',39A2)
      IFILE=IFILE+1
      GO TO 600
 90   IF(ISTAT)35,35,95
 95   PRINT 1000,IUN,ISTAT,NRECS,IFILE
 1000 FORMAT(' TAPE ERR UNIT ',I2,' CODE: ',Z4,I8,' RECS PROCESSED, FILE
     *',I3)
      IFLG=1
      GO TO 35
 99   REWIND 8
      STOP
      END
```

Figure D1. Program Listing

```
:NJ,L      :IO,3,24
:RW,4,6,7
:FG
 Program Reform
 End
 blank
:IO,3,24,8,16,9,17,10,18,5,30
:GO,/TIR,(M)
 Data Card
:XX
```

Figure D2. Control Cards for Reform

APPENDIX E

W_Z METHOD

W_z RATING OF RIDE QUALITY
IMPLEMENTATION FOR FRA/AMTRAK PROGRAMS

BACKGROUND

In 1941, Helberg and Sperling [1] developed a procedure for appraising the running qualities of railroad cars. A series of experiments was conducted to establish the relationship between vibrations and the response of an individual to those vibrations. Tests were conducted in a seated position on a vibrating table at frequencies between 1 and 12 Hz and at amplitudes up to 1 inch. Participants in the experiments were limited to employees of the railroad who had experience in vehicle vibrations. A total of 1,800 tests were conducted.

A formula for computing W_z was derived from these experimental results. W_z was defined as a function of both acceleration level and frequency. There are several points worth noting. First, no distinction was seen between vertical and horizontal vibrations. This conclusion was drawn as a result of testing, as tests were conducted in both vertical and lateral directions. Second, for a given frequency, W_z only increases by 23 percent when the acceleration level doubles in amplitude. Third, on a 5-point scale, where 1 is an excellent ride and 5 a dangerous one, 3 was selected as the lower limit for passenger cars.

In 1968, Sperling [2] wrote a paper which updated the W_z method with respect to automatic computation on a railway vehicle using more modern methods. He describes how the method is used by the German Federal Railway.

In recent times, several articles have been written concerning the W_z method. Pribnow [3] states that the method is useful but somewhat coarse. Andrew [4] feels that the method is outdated and that poor experimental procedures were used. However, he does think that modifications (weighting factors and integration over the entire frequency range) have improved the method.

DESCRIPTION

The W_z method of rading the ride of a rail vehicle has been widely used in recent decades. This method applies a single number to describe the quality of the ride. The instantaneous acceleration is measured and weighted in the frequency domain. This value is squared and averaged over time, after which the 6.67th root is taken. This final number if the W_z rating. Figure E1 is a flowchart of the process. The working units are cm/sec^2 for acceleration.

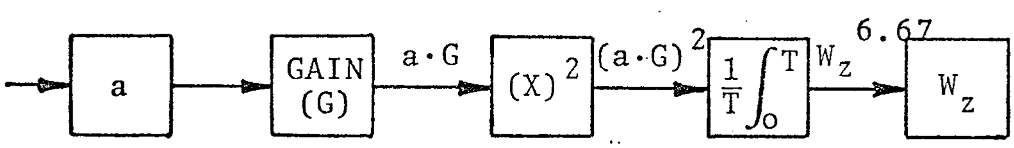


Figure E1. Flowchart of W_z Method

In general

$$W_z = 6.67\sqrt{\frac{0.896}{T}\int_0^T (G \cdot A)^2 \, dt}$$

where

W_z = criterion number

T = total time of data sampled

G = weighting function

A = acceleration level

The rating scheme for W_z is as follows:

W_z	Condition of Ride
1	Excellent
2	Good
3	Satisfactory
4	Car in working order
5	Dangerous

One advantage to the W_z rating process is that a single number can be applied which can describe the quality of the ride. Another advantage is that the W_z method is weighted in the frequency domain and takes into account experimental studies involving actual passenger reactions.

A disagreement between this method and the ISO study involves the frequencies dominated by passenger discomfort. In the W_z method, the frequency band of greatest passenger discomfort occurs at 5 Hz for both lateral and vertical accelerations. In the ISO standard, the frequency band of greatest passenger discomfort occurs at 1 to 2 Hz for the lateral accelerations and at 4 to 8 Hz for vertical accelerations.

An important characteristic of the W_z rating scheme is its insensitivity to the acceleration level. For instance, if the acceleration level is doubled for a given frequency, the W_z rating will only increase by 23 percent. This means that the ratings of most present-day vehicles will fall between 1 and 3.

IMPLEMENTATION

The following parameters were used to implement the W_z method into the computer program VIBES:

G(I)	=	an array of frequency-dependent gains
$G_L(I)$	=	weighted gain (lateral)
$G_V(I)$	=	weighted gain (vertical)
ΔF	=	bandwidth (0.25 Hz) of present RQ software
PSD(I)	=	an array of power spectral density values (in dB WRT 1 g^2 rms/Hz)
PD(I)	=	conversion of PSD values to acceleration as a function of $(cm/sec^2)^2/Hz$ (since the data are recorded in g's)
WZ_V	=	WZ rating in vertical direction
WZ_L	=	WZ rating in lateral direction
$G_L(I)$	=	an array of 120 points (see Table E1)
$G_V(I)$	=	$0.8333 * G_L(I)$

G_L can be approximated as follows:

f(Hz)	G_L
0.25	0.25
0.50	0.43
0.75	0.54
$1.0 \leq f \leq 8.0$	$[-(f-5)^2/40]+1$
$8.0 < f \leq 30.0$	0.948^f

This approximation can be used only if the $G_L(I)$ array is not compatible with available core space.

Then:

$$PD(I) = (980.7)^2 * \text{PSD Level } (g^2/Hz) \text{ for both vertical and lateral}$$

$$SUM_V = 0.896(\Delta f)\sum_{j=1}^{120} G_V(I) * PD_V(I)$$

$$SUM_L = 0.896(\Delta f)\sum_{j=1}^{120} G_L(I) * PD_L(I)$$

$$WZ_V = SUM_V ** 0.15$$

$$WZ_L = SUM_L ** 0.15$$

The ride can then be rated as follows:

W_z	Rating
1.0	Excellent
1.5	Nearly excellent
2.0	Good
2.5	Nearly good
3.0	Satisfactory (upper limit/passenger cars)
3.5	Barely satisfactory
4.0	Operable (upper limit/freight cars)
5.0	Dangerous

TABLE E1. $G_L(I)$

I	Freq. (Hz)	$G_L(I)$	I	Freq. (I)	$G_L(I)$	I	Freq. (I)	$G_L(I)$
1	0.25	0.25	28	7.0	0.90	55	13.75	0.45
2	0.5	0.43	29	7.25	0.87	56	14.0	0.45
3	0.75	0.54	30	7.5	0.85	57	14.25	0.44
4	1.00	0.62	31	7.75	0.82	58	14.5	0.43
5	1.25	0.68	32	8.0	0.80	59	14.75	0.42
6	1.50	0.73	33	8.25	0.77	60	15.0	0.41
7	1.75	0.77	34	8.5	0.75	61	15.25	0.41
8	2.00	0.80	35	8.75	0.72	62	15.5	0.40
9	2.25	0.83	36	9.0	0.70	63	15.75	0.40
10	2.50	0.86	37	9.25	0.69	64	16.0	0.39
11	2.75	0.89	38	9.5	0.67	65	16.25	0.39
12	3.00	0.90	39	9.75	0.65	66	16.5	0.38
13	3.25	0.93	40	10.0	0.64	67	16.75	0.37
14	3.50	0.95	41	10.25	0.62	68	17.0	0.36
15	3.75	0.96	42	10.5	0.61	69	17.25	0.36
16	4.00	0.98	43	10.75	0.60	70	17.5	0.35
17	4.25	0.99	44	11.0	0.58	71	17.75	0.35
18	4.50	0.99	45	11.25	0.57	72	18.0	0.34
19	4.75	1.0	46	11.5	0.56	73	18.25	0.34
20	5.00	1.0	47	11.75	0.55	74	18.50	0.33
21	5.25	0.99	48	12.0	0.54	75	18.75	0.33
22	5.50	0.98	49	12.25	0.53	76	19.0	0.32
23	5.75	0.97	50	12.5	0.51	77	19.25	0.32
24	6.00	0.96	51	12.75	0.50	78	19.50	0.31
25	6.25	0.95	52	13.0	0.48	79	19.75	0.31
26	6.50	0.93	53	13.25	0.47	80	20.0	0.30
27	6.75	0.92	54	13.5	0.46	81	20.25	0.30

I	Freq. (I)	G_L	I	Freq. (I)	$G_L(I)$
82	20.5	0.30	109	27.25	0.21
83	20.75	0.29	110	27.5	0.21
84	21.0	0.29	111	27.75	0.21
85	21.25	0.28	112	28.0	0.21
86	21.5	0.28	113	28.25	0.20
87	21.75	0.27	114	28.5	0.20
88	22.0	0.27	115	28.75	0.20
89	22.25	0.27	116	29.0	0.20
90	22.5	0.26	117	29.25	0.19
91	22.75	0.26	118	29.50	0.19
92	23.0	0.26	119	29.75	0.19
93	23.25	0.25	120	30.0	0.19
94	23.5	0.25			
95	23.75	0.24			
96	24.0	0.24			
97	24.25	0.24			
98	24.5	0.23			
99	24.75	0.23			
100	25.0	0.23			
101	25.25	0.23			
102	25.5	0.23			
103	25.75	0.23			
104	26.0	0.22			
105	26.25	0.22			
106	26.5	0.22			
107	26.75	0.22			
108	27.0	0.21			

COMPARISON OF ISO AND W_Z

In comparing the W_z method and the alternate ISO standard, one must first investigate the weighting function used with each method. A comparison of the lateral and vertical weighting functions for the ISO criteria is shown in Figure E2. Figure E3 shows the same comparison for the W_z rating scheme. It can be seen that there are major differences in the weighting functions. Figures E4 and E5 compare the weighting functions of the two methods. In the vertical channel, the two are nearly identical. In the lateral directions, there is a notable difference. The greatest sensitivity in the ISO standard is in the 1 to 2 Hz range. The greatest sensitivity in the W_z method is in the 6 to 8 Hz range.

Next, we can make a comparison of the two methods. Figure E6 gives a flowchart depicting this comparison. There is, in general, no difference in the manner in which the two methods are used. However, the two major differences involve the shape of the weighting function and the final conversion to exposure time or W_z rating. We can investigate a direct comparison of the two methods by plotting the results versus $\hat{A}$, an intermediate value of rms acceleration. hese results are shown in Figure E7.

Finally, we can make a comparison of the ISO and alternate ISO standards. A flowchart is seen in Figure E8. The greatest discrepancy occurs in the method of determining the final exposure time. In one, the results are summed over all frequencies. In the other, there is no summation conducted. The exposure time is computed for each frequency, and the least exposure time is given for the final criterion.

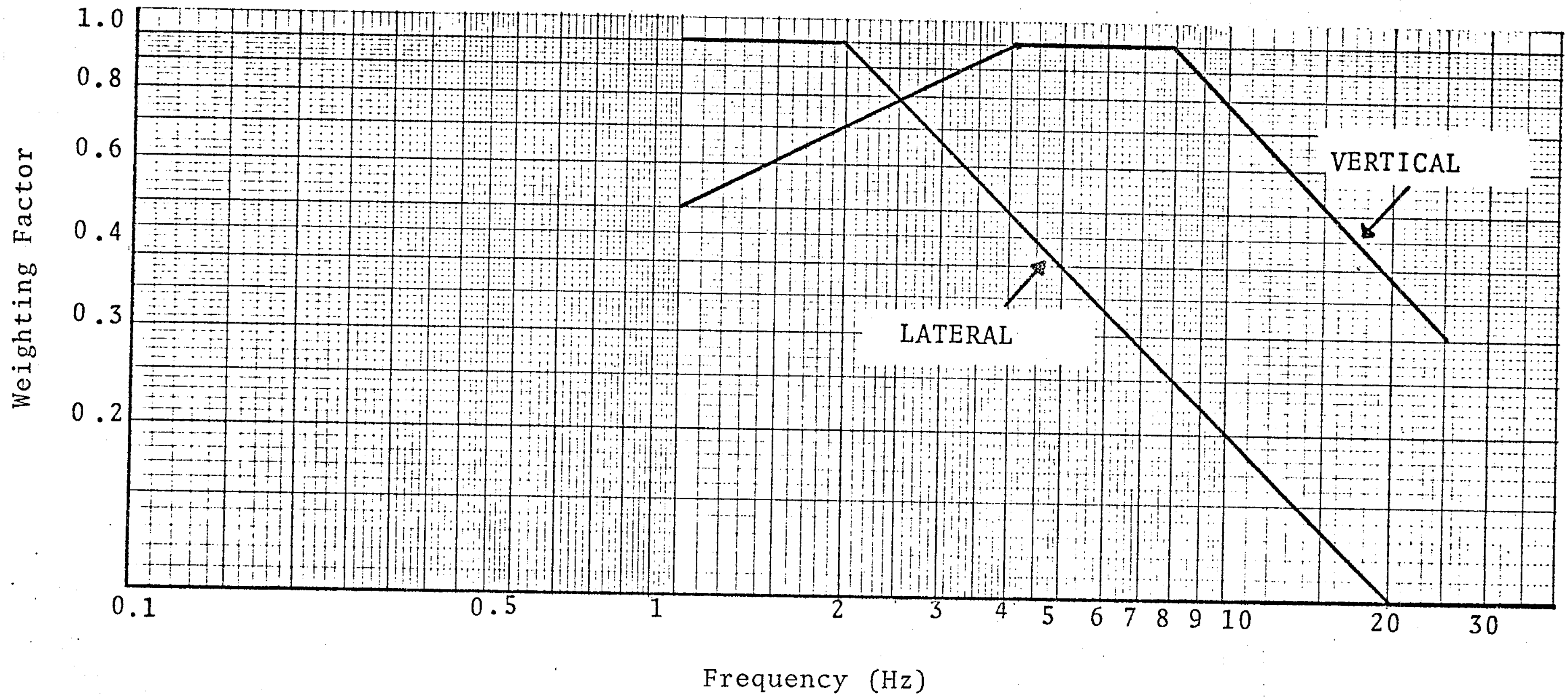


Figure E2. Comparison of Lateral and Vertical ISO Weighting Function

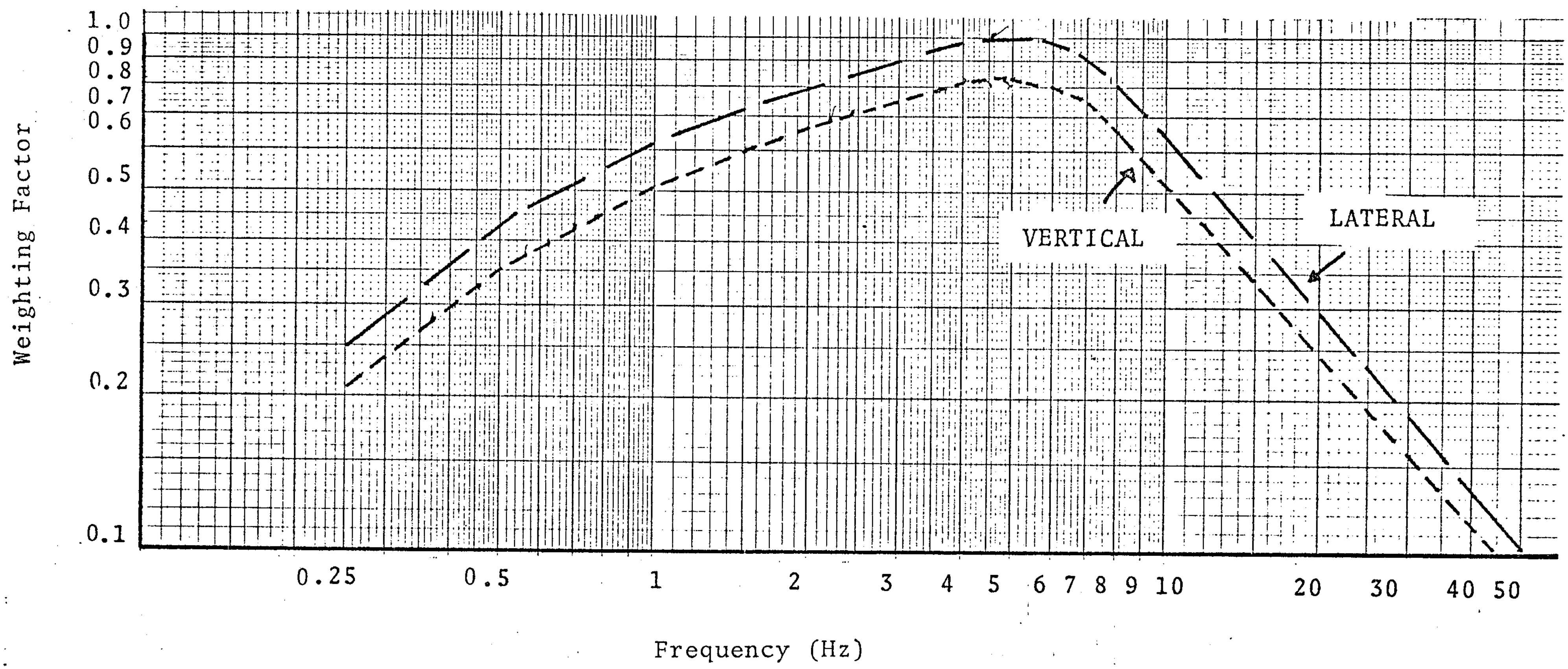


Figure E3. Comparison of Lateral and Vertical W_z Weighting Function

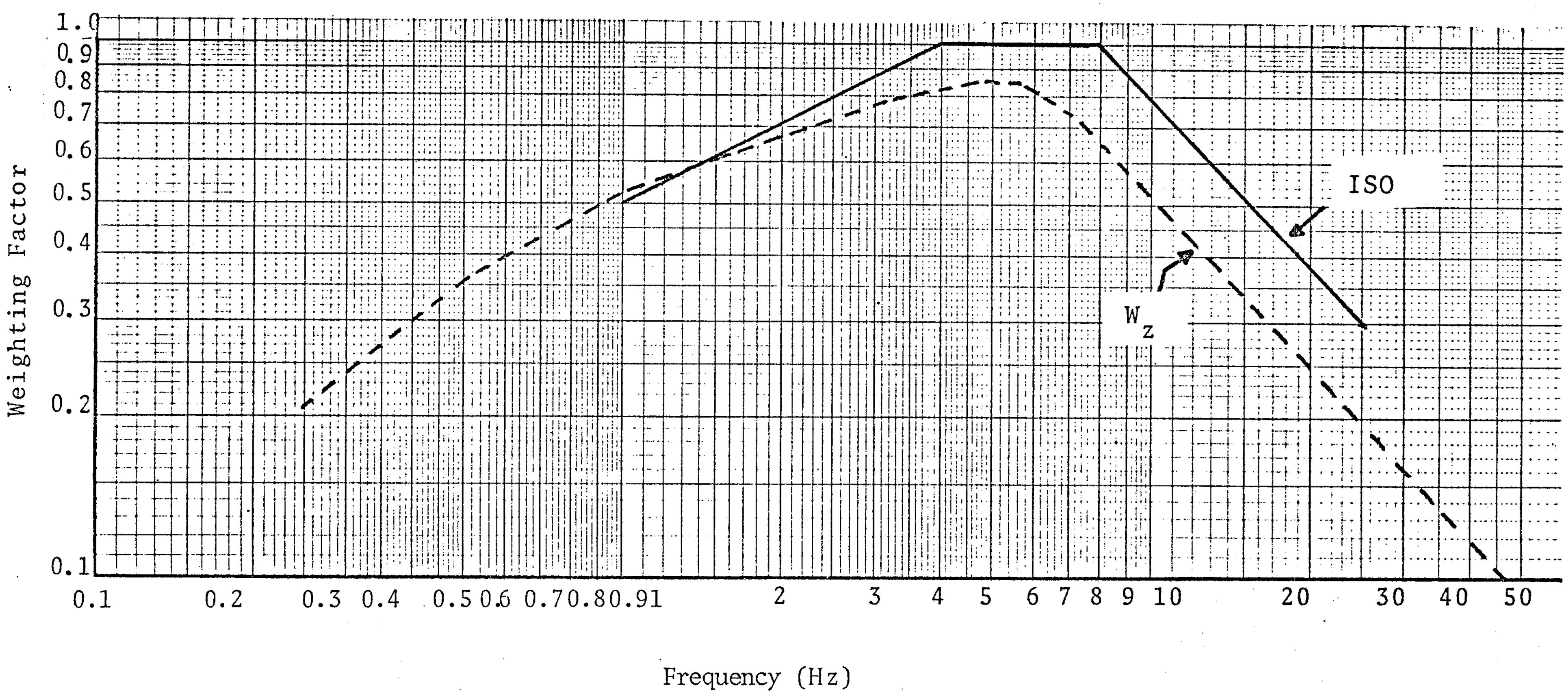


Figure E4. Comparison of ISO and W_z Weighting Function - Vertical

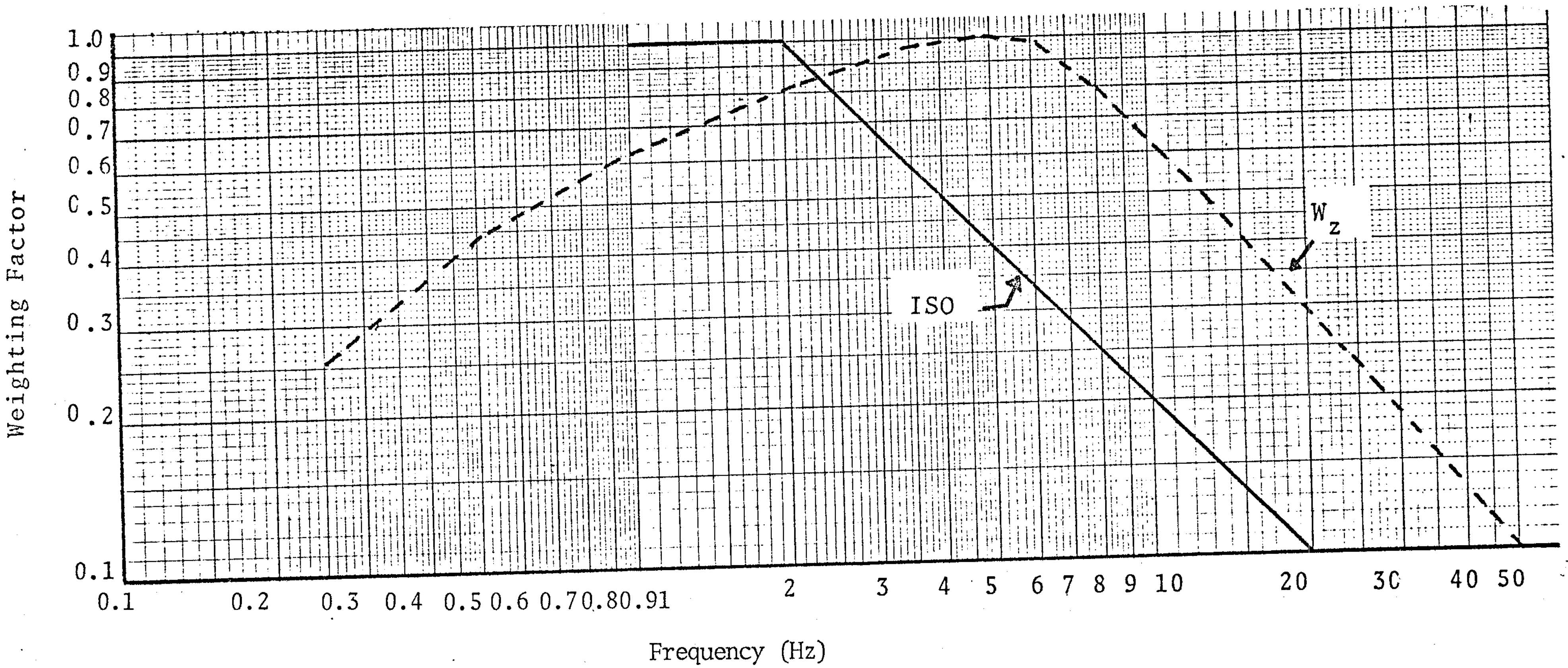


Figure E5. Comparison of ISO and W_z Weighting Function - Lateral

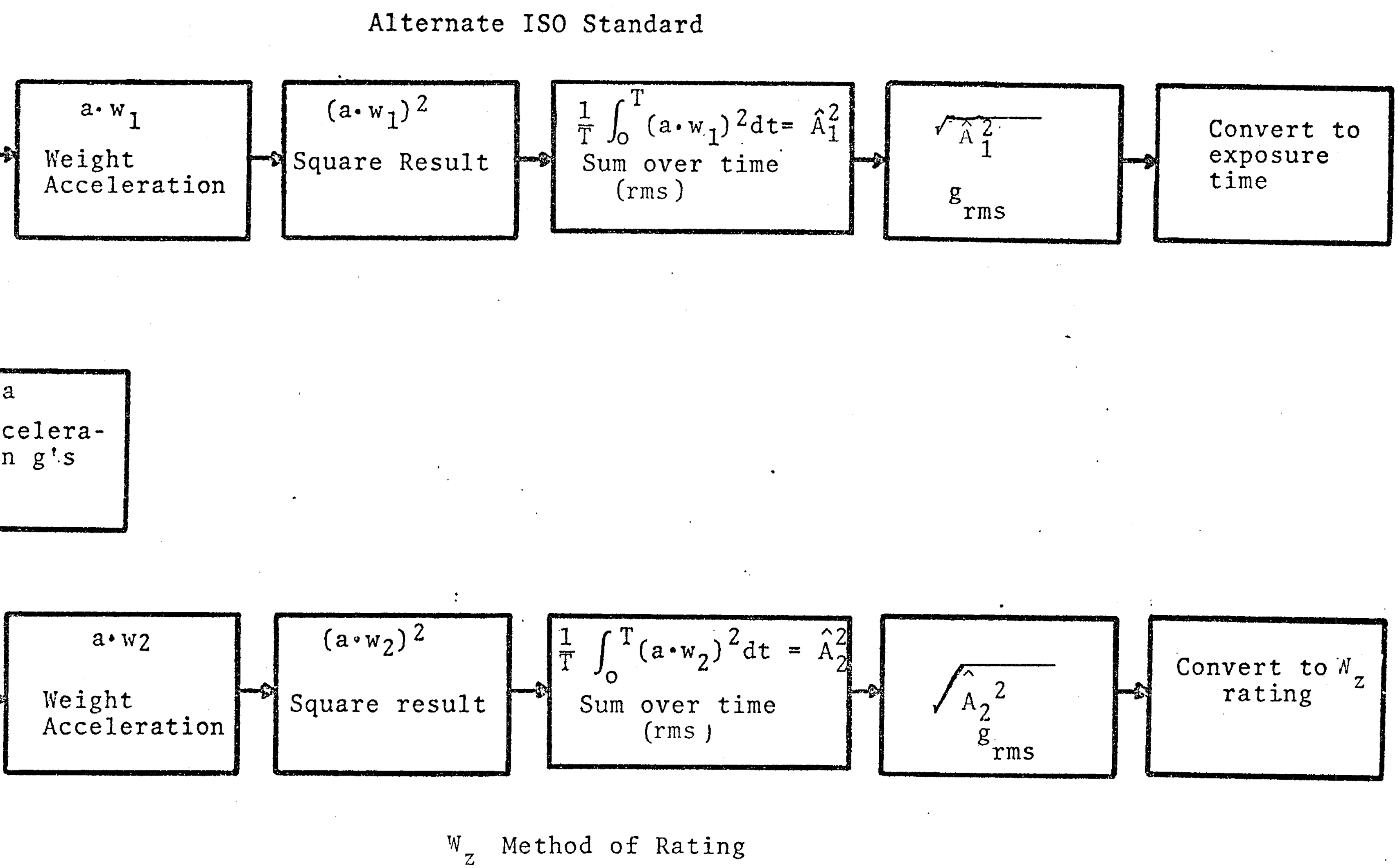


Figure E6. Comparison of W_z and Alternate ISO Standard

ISO EXPOSURE TIME AND W_z RATING

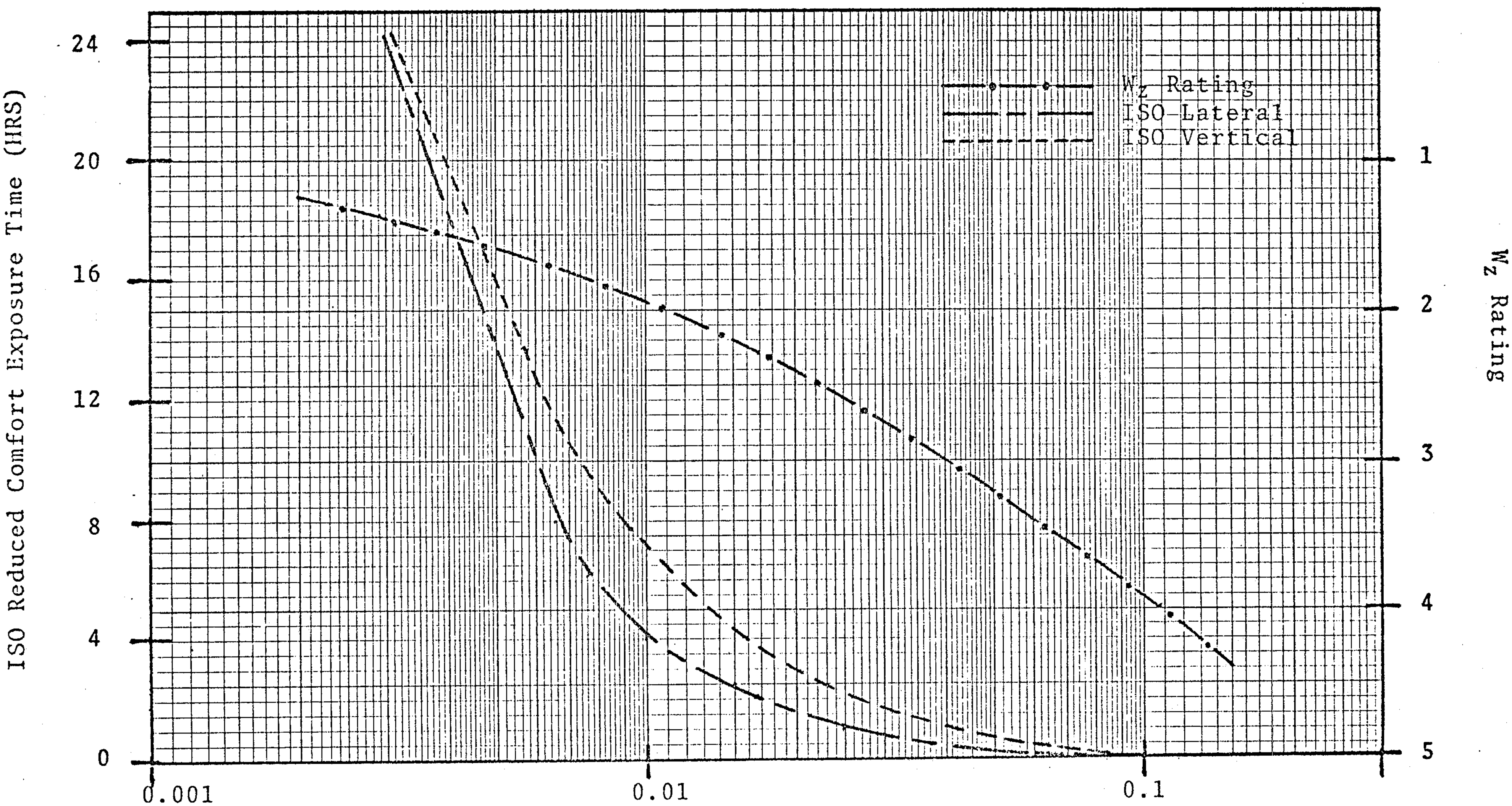


Figure E7. ACCELERATION LEVEL (g's)

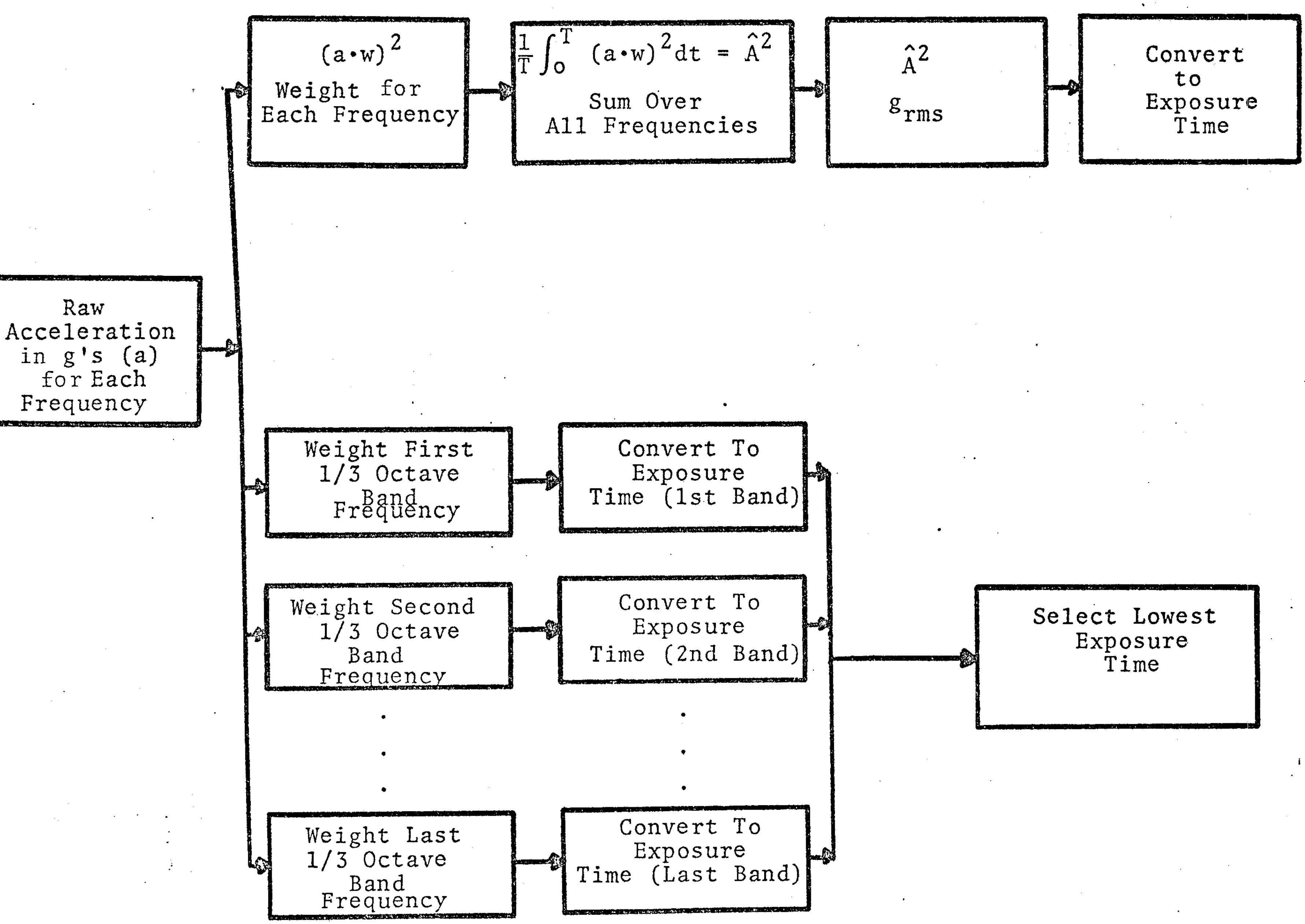


Figure E8. ISO CRITERIA

REFERENCES

[1] Helberg, W. and Sperling, I.E., "Verfahren zur Beurteilung der Laufeigenschaften von Eisenbahnwagen." Organ fur die Fortschutte des Eisenbahnwesens, 96(12):177-187, June 15, 1941. English translation, "A Procedure for Appraising Running Qualities of Railroad Cars", translated from the German by Leon Narshak, Research Information Service, Chicago, IL.

[2] Sperling, I.E., "Stand der Laufgutebestimmungen, Messund und Auswertung," Eisenbahntechnik, 1968. English translation, "Position of Ride Quality Analysis, Measurement and Computation," 1968, Eisenbahntechnik, translation by University of New Hampshire, Center for Industrial and Institutional Development.

[3] Prinbnow, Hans-Hermann, "A Simplified Method for Comparative Evaluation of Ride Quality of Rail Vehicles,", Leichtbau der Verkehrsfahrzeuge, 19 May 1975, pp 101-103.

[4] Andrew, Ian, "Ride Index Obsolete," Rail International, August 1975, p 319.

APPENDIX F

INSTRUMENTATION CAPABILITIES

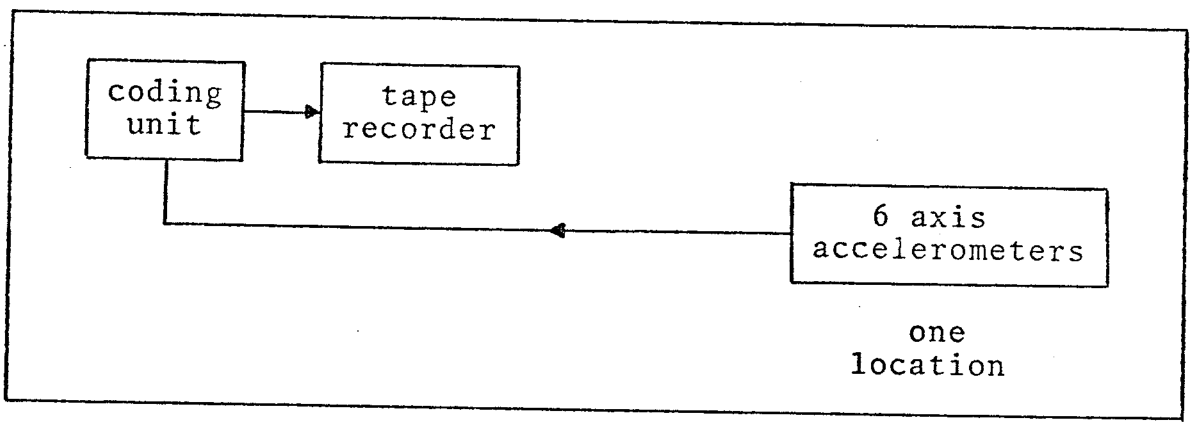
In the past, ENSCO had the capability of collecting vehicle vibration data using a 6-axis accelerometer package. This package provided translational and angular information concerning the motion of the vehicle. Each of the two packages was completed with tape recorder, coding unit, and accelerometer package. The major advantage of this system was that both angular and linear acceleration data could be collected at a specified location in the vehicle. Several disadvantages existed. The major disadvantage was that data could only be collected at one location in the vehicle. A second recorder was required to collect data in two locations, either within the vehicle or in two separate vehicles. Additional manpower was also necessary to use a second recording system. A second disadvantage was that the angular accelerometers required more maintenance than the linear ones and were more difficult to examine. Table F1 indicates ENSCO's past ride quality instrumentation capabilities. Figure F1 illustrates packages 1 or 2.

Table 1. Previous Instrumentation Capabilities

System 1:	"B" tape recorder "B" coding unit "B" 6-axis accelerometers Can collect six channels (three linear and three angular) at one location.
System 2:	"C" tape recorder "C" coding unit "C" 6-axis accelerometers Can collect six channels (three linear and three angular) at one location.

As further experience was gained, it was noted that, in collecting data on two vehicles at the same time, it would be more efficient to collect and record the data on one recorder. This would eliminate a second recorder and would ignore the angular accelerometers. In this case, only translational acceleration data would be collected. This was accomplished through the use of a junction box which separated the signals. Table F2 summarizes the expanded capabilities gained by using a junction box. Figure F2 illustrates this system.

Figure F1. System 1 or 2

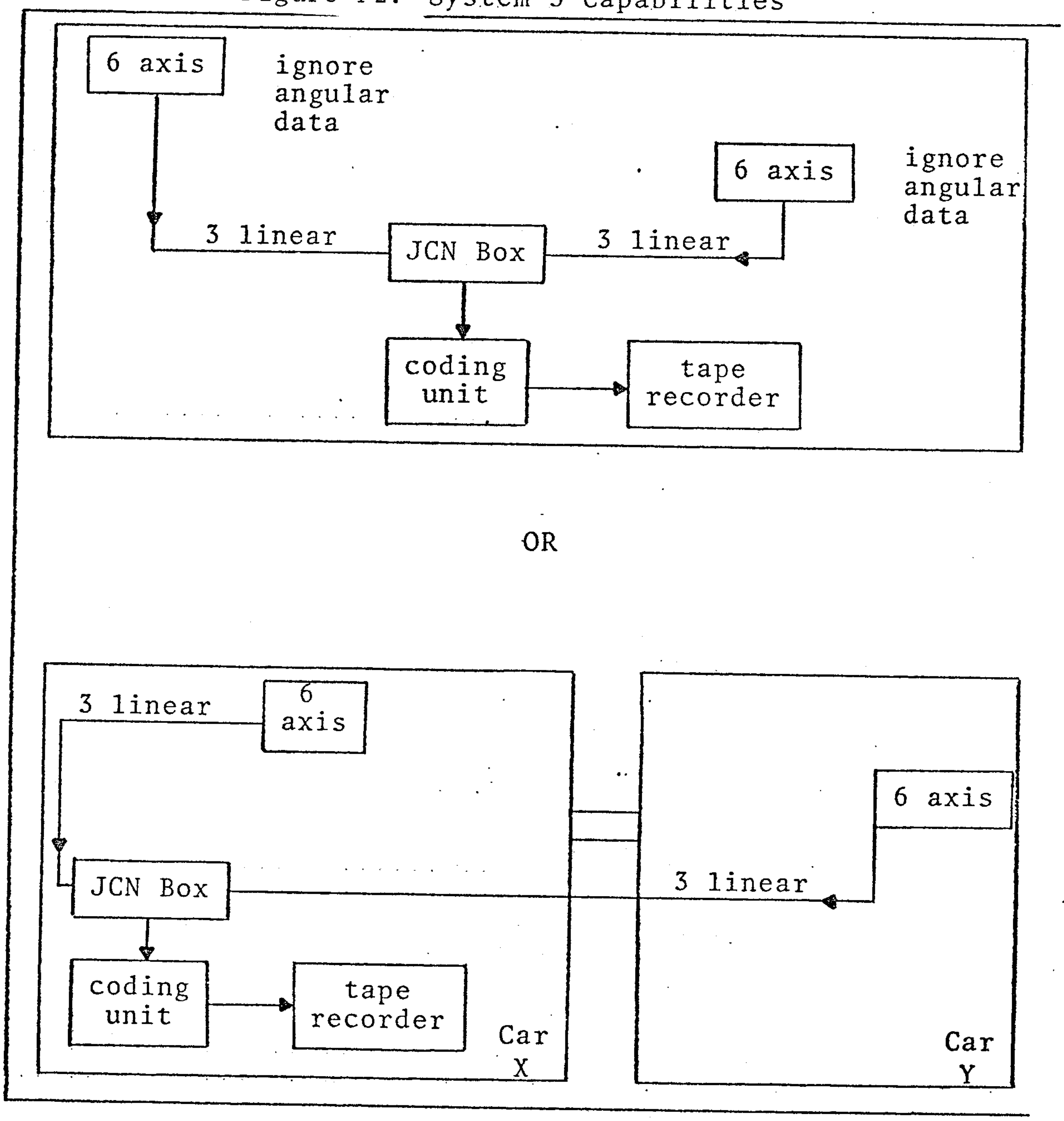


capabilities gained by using a junction box. Figure 2 illustrates this system.

Table F2. Additional Capabilities

System 3:	"B" Recorder "B" Coding Unit "B" Junction Box "B" 6-Axis Accelerometers "C" 6-Axis Accelerometers
	-with appropriate cabling, is able to collect data (linear only) at two locations within a vehicle
	-with appropriate cabling, is able to collect data (linear only) at identical locations in two different vehicles
	-is not able to collect angular data

Figure F2. System 3 Capabilities



Although System 3 is more effiecint, it still required the use of two bulky accelerometer systems, each containing three angular accelerometers not being used.

To provide a better system, a set of three (one back-up) triaxial accelerometer systems was built. Each triaxial package contains three linear accelerometers only. This system would replace System 3 by simply replacing accelerometer packages "B" and "C" with the smaller "D" and "E" units, and would provide the expanded capability of two fully independent systems. Table F3 defines the various configurations that can presently be used in collecting data.

The present inventory of ride quality instrumentation includes the following:

(2) Tape recorders
(2) Coding units
(2) 6-axis accelerometer systems
(3) Triaxial accelerometer systems
(2) Cables 30 feet long
(2) Cables 150 feet long
(2) Cables 6 feet long

With a large amount of instrumentation and various configurations to choose from, it may be difficult at times to select the right equipment for a particular test. Table F4 should be used when selecting test instrumentation. All the instrumentation is interchangeable and requires no additional calibration.

In addition, a small protable ride quality meter may be used to examine the ride of a vehicle and indicate the resulting

Table F3. Various Potential Configurations

Configuration	Recorder	Coding Unit	JCN Box	Accelerometer		Two Locations	Two Vehicles
1	B	B	None	B	-	No	No
2	C	C	None	C	-	No	No
3	B	B	B	B	C	Yes	Yes
4	C	C	C	D	E	Yes	Yes
5	B	B	B	D	E	Yes	Yes
6	C	C	C	B	C	Yes	Yes

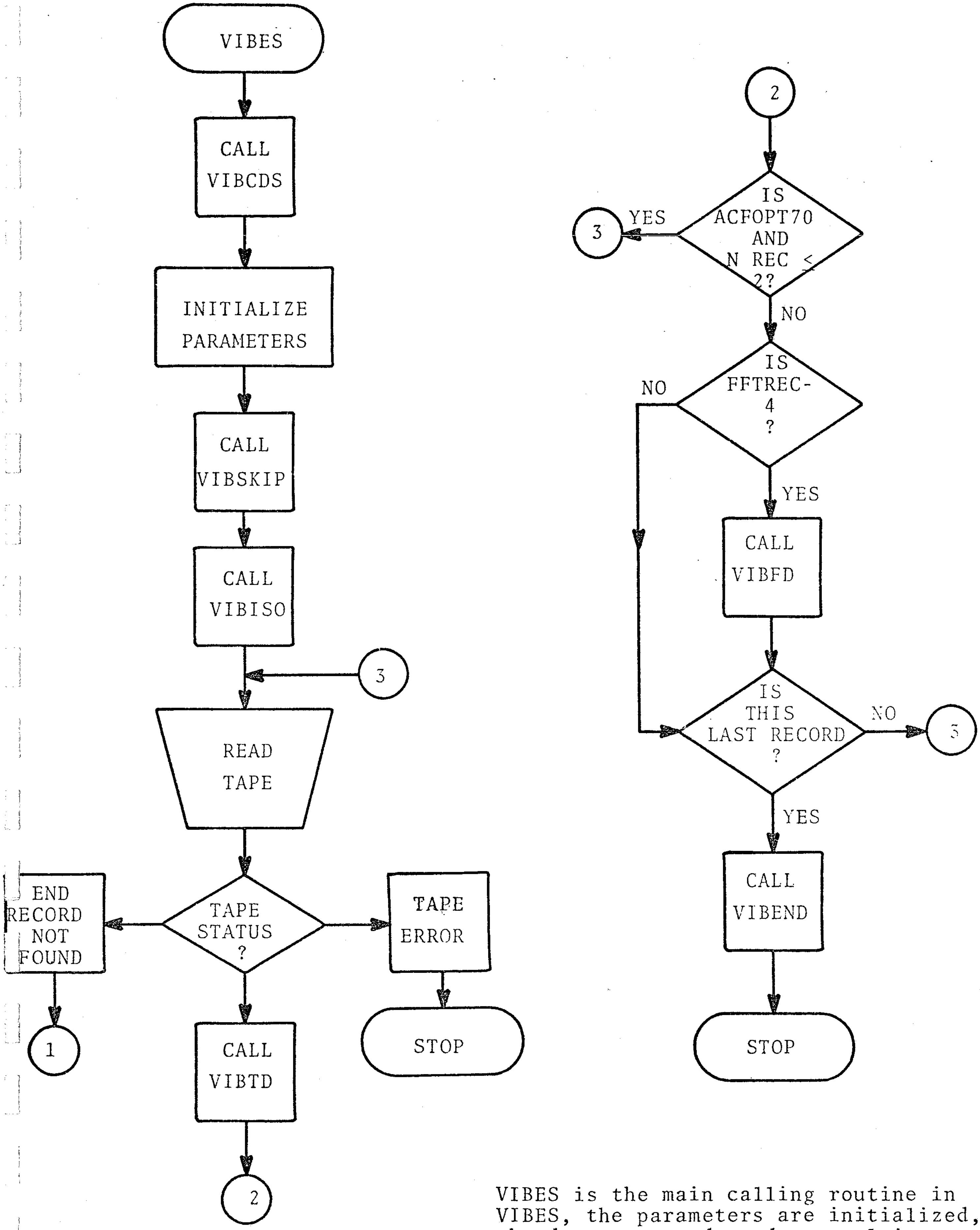
Table F4. Selection of Instrumentation

Type of test to be conducted	Primary* Configuration	Length of Cables (ft)	Back-up Configuration
Collection of angular acceleration data at one location	1	6	2
	2	6	1
Collection of linear data at two locations within vehicle	4	30	3
	5	30	6
Collection of linear data at identical locations within two different vehicles	4	150	3
	5	150	6
Collection of linear acceleration data at one location	1	6	2
	2	6	1

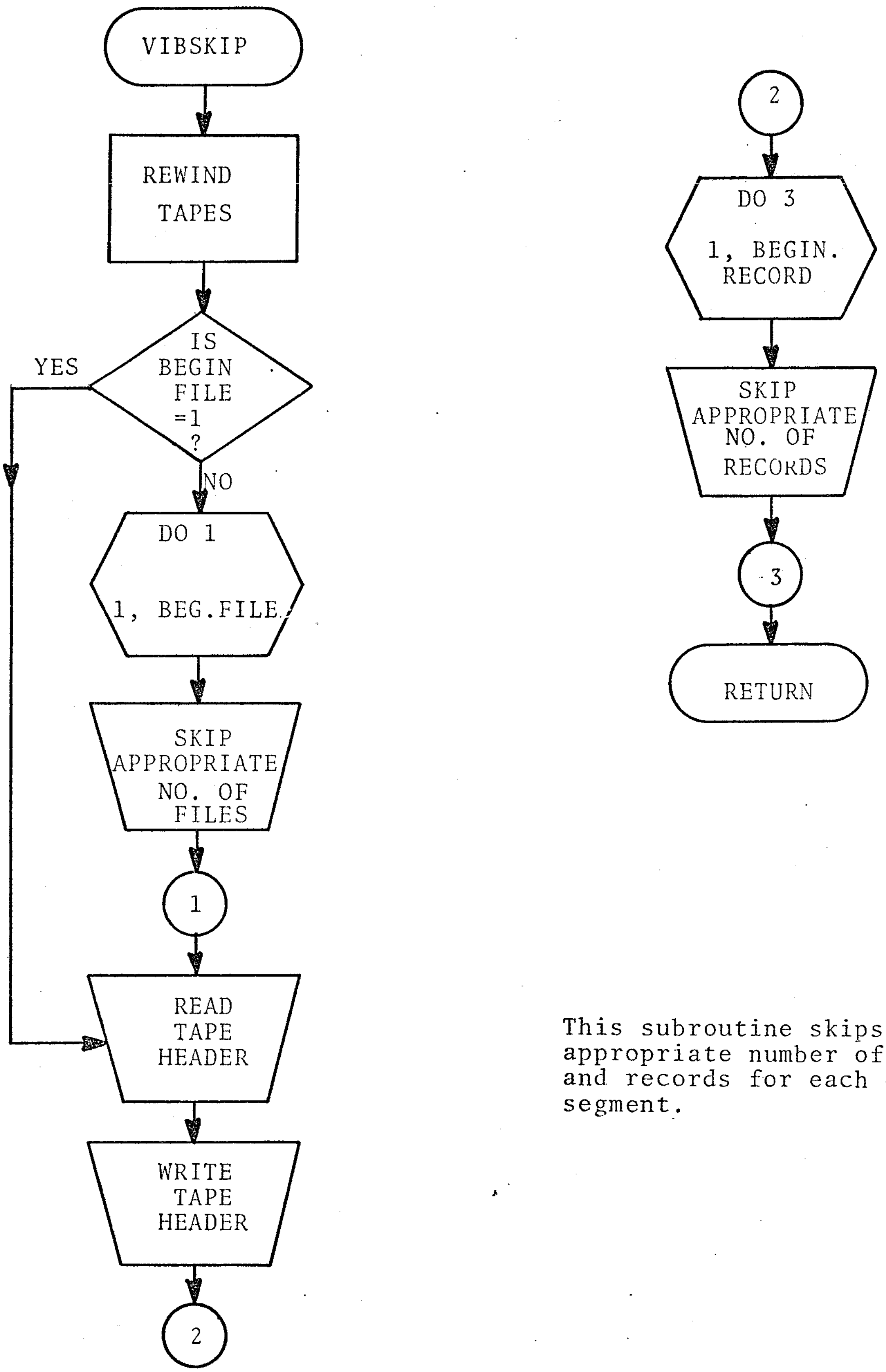
*See Table F3 for a description of the configurations

APPENDIX G

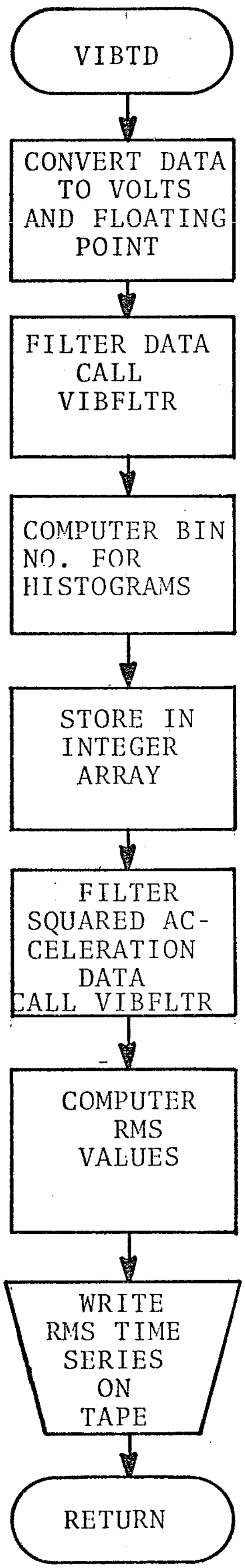
SOFTWARE FLOW CHARTS



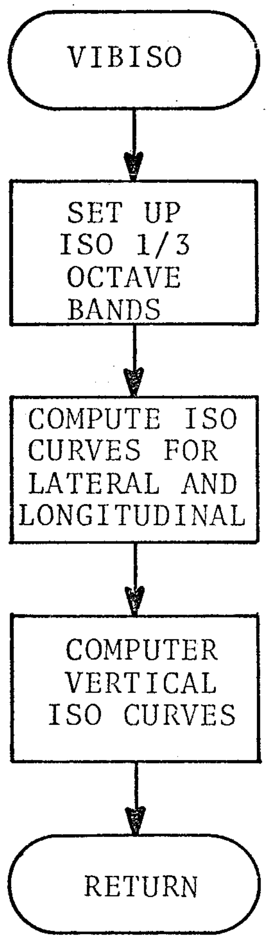
VIBES is the main calling routine in VIBES, the parameters are initialized, the data are read, and control is given for calling subroutines.



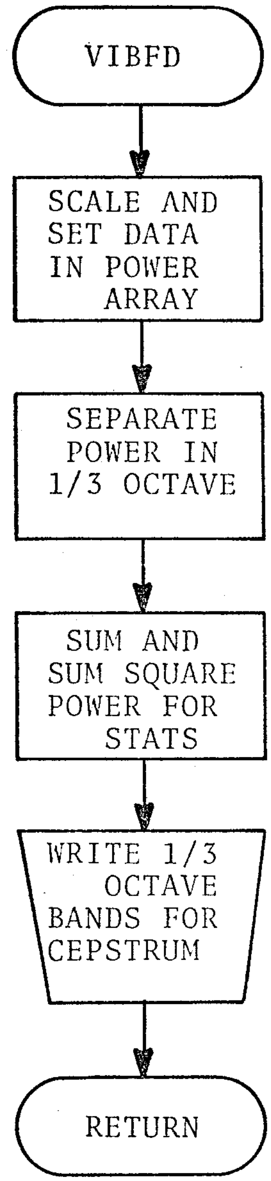
This subroutine skips the appropriate number of files and records for each data segment.



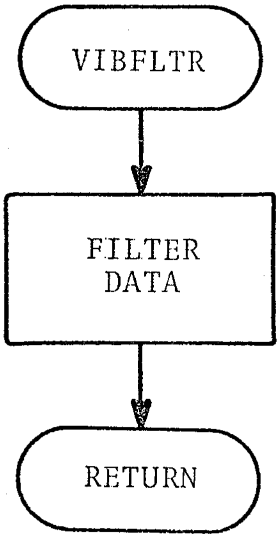
This subroutine low pass filters the data, computes the histograms, high pass filters the data, and computes a time series of the rms accelerations.



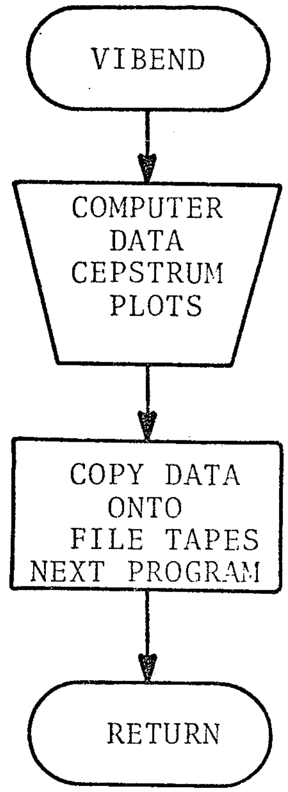
This subroutine sets up the one-third octave band filters and determines the ISO curves for the three linear degrees of freedom.



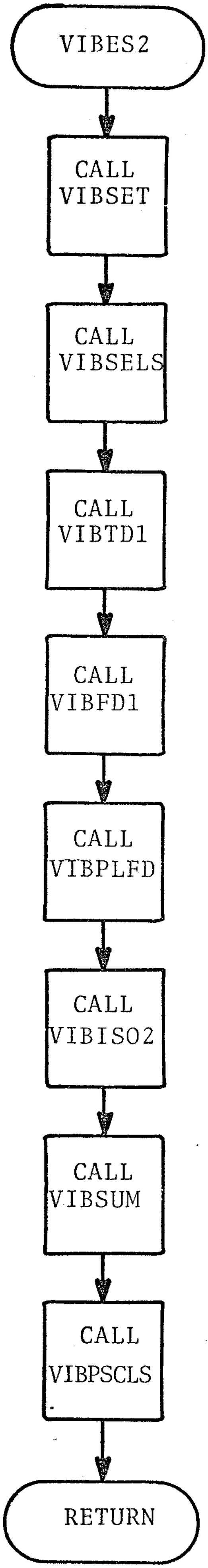
This subroutine scales the data for use in the power spectral densities.



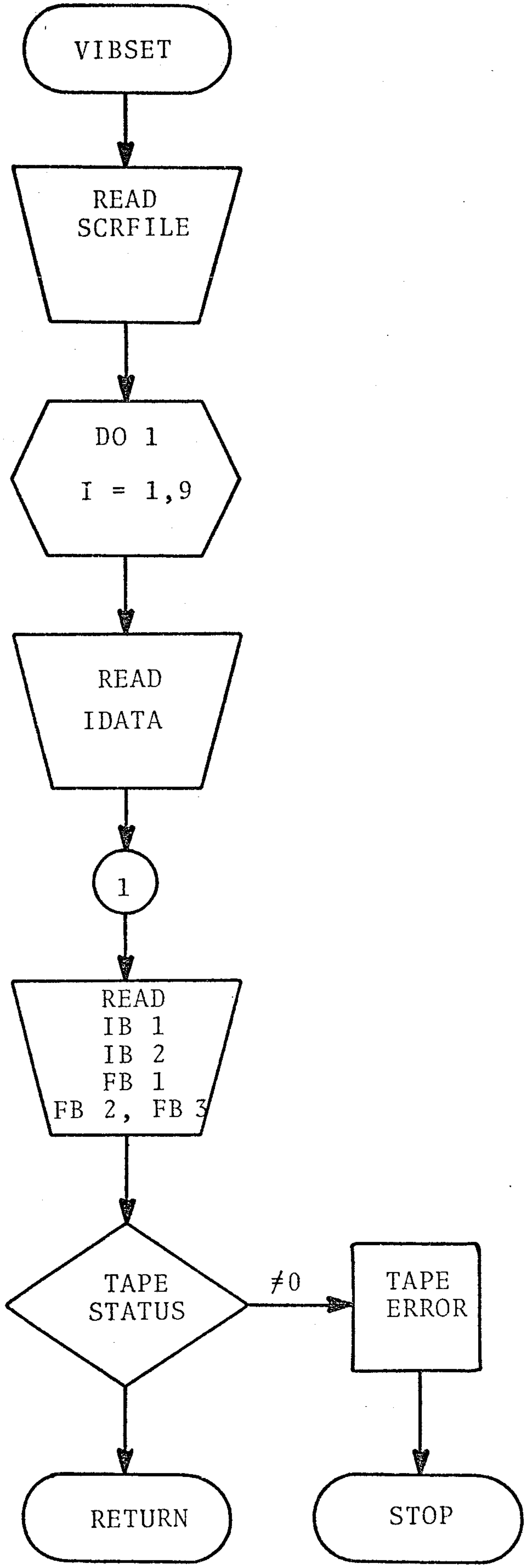
This subroutine is the filter used in the data processing.



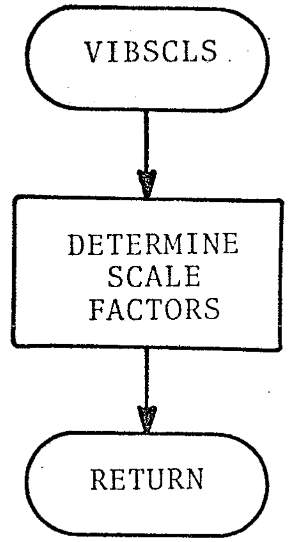
Due to core space, this subroutine outputs data onto a file to be read by the next program.



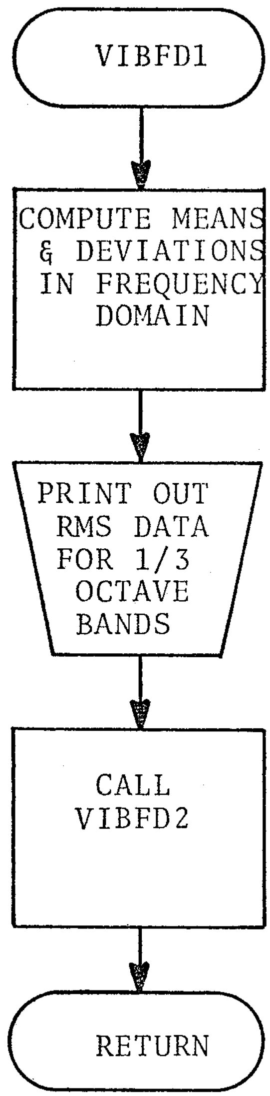
This subroutine is the main program for the second phase of the data processing and controls the calling sequence.

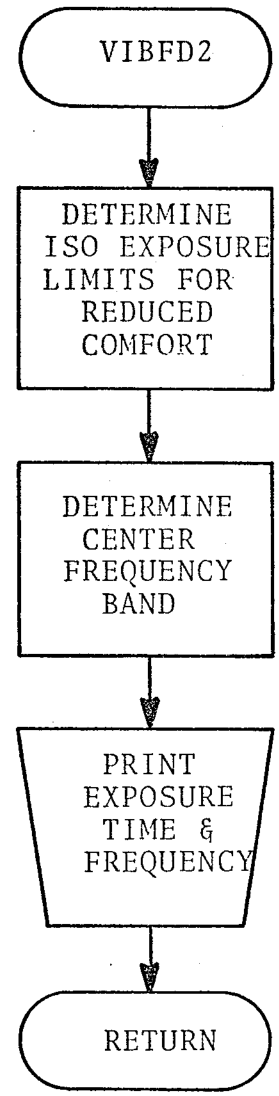


This subroutine inputs various parameters from tape.



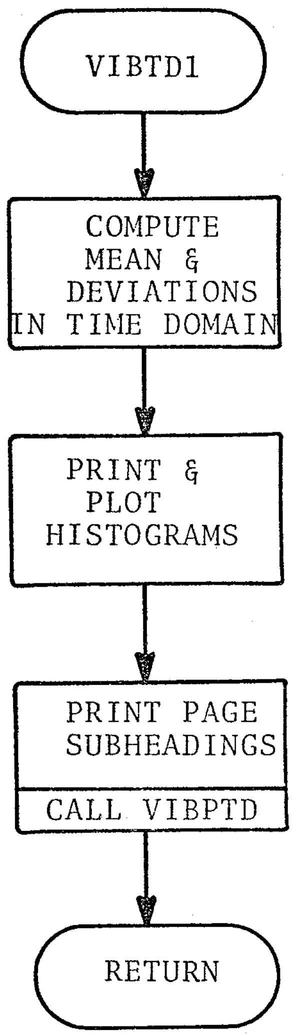
This subroutine determines the scale factors used in correlating the data.



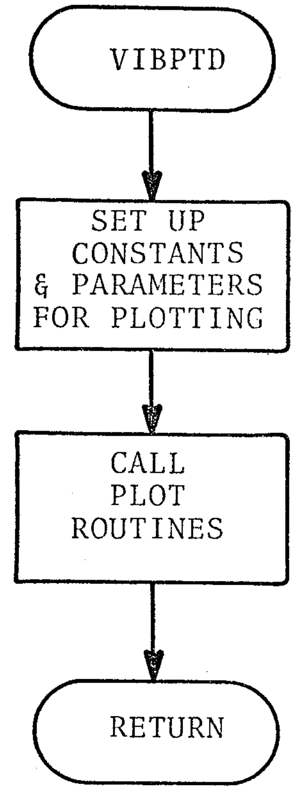


VIBFD1 computes the means and deviations in the frequency domain and prints out the rms data in one-third octave bands.

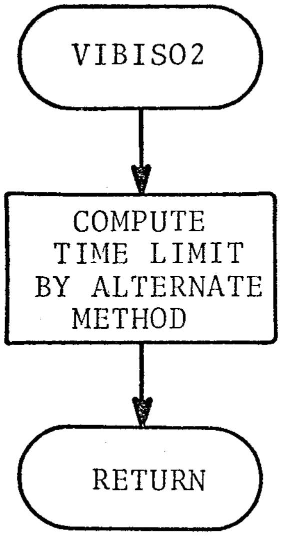
VIBFD2 determines the ISO exposure limits for the reduced comfort criteria, determines the center frequency band, and prints the results.



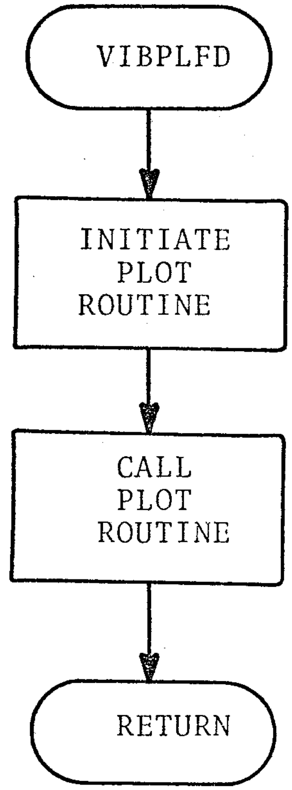
This subroutine sets up the parameters for plotting the probability density and the distribution function.



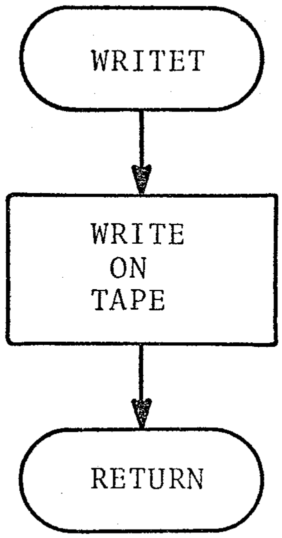
This subroutine plots out the probability density estimates and the distribution function estimates.



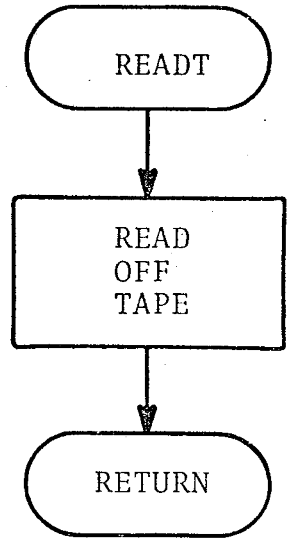
VIBISO2 computes the time limits for the alternate ISO method.



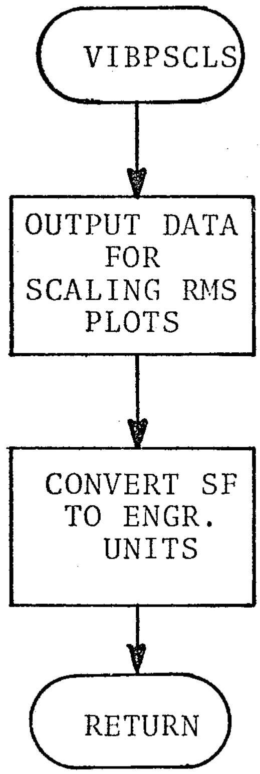
This routine sets up the parameters for plotting the PSD's.



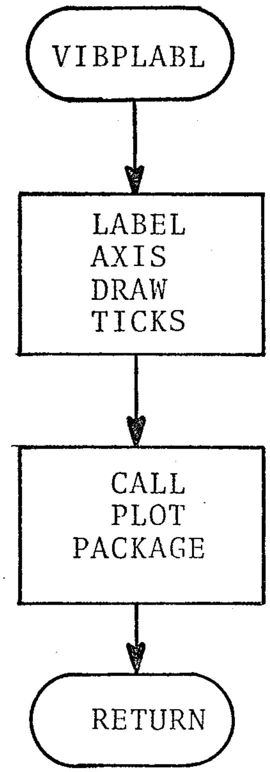
This subroutine writes data on magnetic tape.



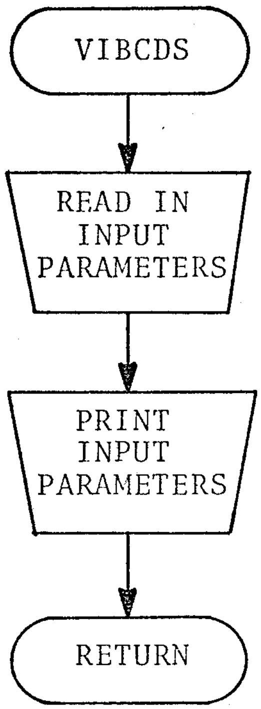
This subroutine reads data off magnetic tape.



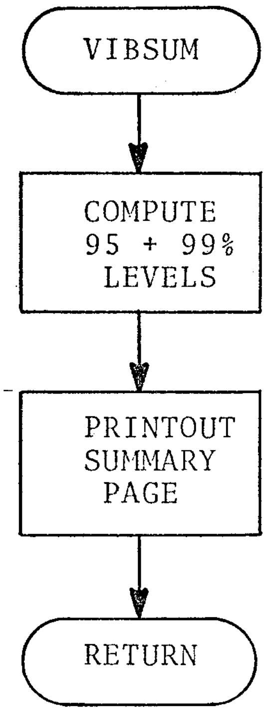
VIBPSCLS outputs data for scaling the rms plots.



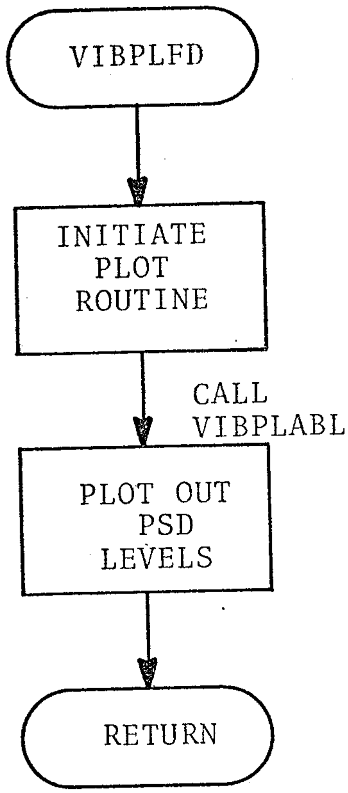
This is a general plot subroutine.



This subroutine reads (off cards) the input data for the program.



This subroutine computes the 95% and 99% levels, and prints out the summary page.



This subroutine sets up the plot parameters for the PSD's.