Contract No. DOT-FR-64113

RIDE QUALITY TEST RESULTS

CANADIAN LRC TESTING

IN SUPPORT OF

TEST REQUEST RR-251

June 1977

Prepared for:

DEPARTMENT OF TRANSPORTATION
Federal Railroad Administration
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EXECUTIVE SUMMARY

This report describes the results of test RR-251, whose purpose was to collect vehicle vibration data on the Canadian LRC locomotive and coach. Data was collected using tri-axial linear accelerometers placed over both the trucks of the locomotive and over the trailing truck of the coach.

Details of the results are given in this report along with short descriptions of the hardware, software and test procedures. Results indicate that the LRC coach provides a comfortable ride on both tangent and curved track. A discussion and analysis of a banking failure that occurred during the test is also presented in this report.

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1.0 INTRODUCTION

Ride quality is principally a subjective estimate of how well a vehicle isolates a passenger from disturbances externally produced by irregularities in a roadbed. Although ride quality in this report alludes primarily to railroads, the concept is applicable to airplanes, buses, autos, etc.

Passenger evaluation of ride quality is generally quantified using a statistical approach. After riding a particular vehicle or vehicles a number of individuals are then asked to subjectively rate the ride as good, fair, bad, or they may be asked to rank different vehicles against each other. The results are assigned numerical values and averaged to obtain a numerical values and averaged to obtain a numerical rating of ride quality.

It has been known for many years that vertical, lateral, and to a lesser degree, longitudinal accelerations experienced within the vehicle body correlate with subjective estimates of ride quality, although not necessarily on a one-to-one basis. Also, only accelerations over a certain frequency range correlate with ride quality. More recent studies have shown that the correlation is even greater if certain frequencies are weighted or given more importance than other frequencies. In fact, an ISO* Human Response Curve has emerged which can be used to weight the acceleration signal obtained for estimating ride quality.

The measurement of vehicle acceleration is also important in the area of freight car operation as acceleration amplitudes generally correlate directly with lading damage. This is because the acceleration levels are normally a direct measure of energy input to the lading system. Where specific mechanical

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*International Standardization Organization resonances or similar frequency response phenomena are known to exist, the measured accelerations can be weighted to obtain a better measure of their effect.

The Federal Railroad Administration (FRA) is involved in the improvement of rail vehicle ride quality. As a tool to aid in the study of ride quality, the FRA retained ENSCO, Inc. to develop several instruments to be used in the measurement of accelerations as a measure of ride quality.

Recently, AMTRAK has become aware of the problems of maintaining high speeds for passenger vehicles in regions having much curved track. FRA and AMTRAK are presently involved in testing a Canadian LRC (Light, Rapid, and Comfortable) vehicle which has a specially designed banking system and permits travel at high speeds on curved track. This type of vehicle would greatly add to the comfort of the passengers during such a trip.

The LRC consist was made up of a locomotive and one coach. This coach featured a newly designed tilting body suspension system that allows high speed operation around curves. This banking system enables the coach body to tilt up to 8-1/2 degrees. This provides a comfortable ride even on bad curves.

The locomotive weighs 218,000 pounds and is geared for 120 mph using 2300 horsepower. The overall height is 11'9", the width is 10'5" and the distance between couplers is 67'11". The coach weight is 93,000 pounds with a height of 11'3" and a maximum width of 10'5". The distance between couplers is 85'0".

ENSCO's role in the testing of the LRC was to collect vibration data on both the LRC locomotive and LRC coach, and determine their ride quality response at designated speeds. The overall approach used in the LRC testing is shown in Figure 1. After instrumenting the vehicles and collecting the data, analysis was performed using basic techniques and software reduction programs. A description of the test, reduction techniques and results are given in this report.

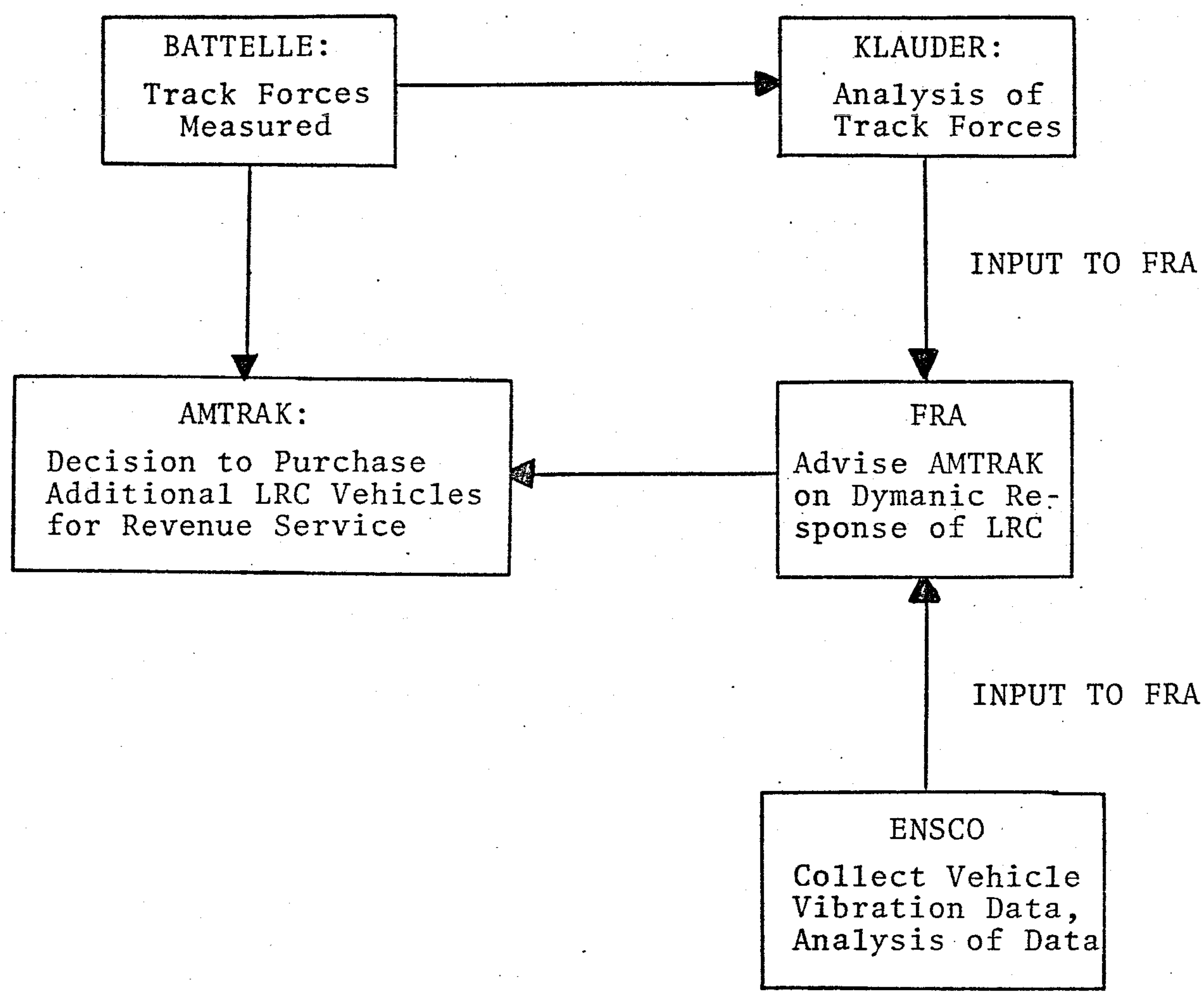


Figure 1. ENSCO's Role in LRC Testing

2.0 TEST DESCRIPTION

The purpose of this test was to collect vehicle vibration data on the Canadian LRC in support of FRA, Office of Passenger Systems requirements. Locomotive and coach vibration data were recorded using analog tape recorders and tri-axial accelerometer packages. Three accelerometers were located at each of the following locations:

1) Leading Truck of LRC Locomotive
2) Trailing Truck of LRC Locomotive
3) Trailing Truck of LRC Coach

At each location, lateral, vertical, and longitudinal accelerations were measured at the center of the truck position, as shown in Figure 2.

Complete, handwritten logs were maintained during the testing and are included in Appendix A.

The transducers were located over the leading and trailing trucks of the LRC locomotive and over the trailing truck of the coach. Data collected included the following:

- Vertical Acceleration (leading truck, locomotive)
- Lateral Acceleration (leading truck, locomotive)
- Longitudinal Acceleration (leading truck, locomotive)
- Vertical Acceleration (trailing truck, locomotive)
- Lateral Acceleration (trailing truck, locomotive)
- Longitudinal Acceleration (trailing truck, locomotive)
- Vertical Acceleration (trailing truck, coach)
- Lateral Acceleration (trailing truck, coach)

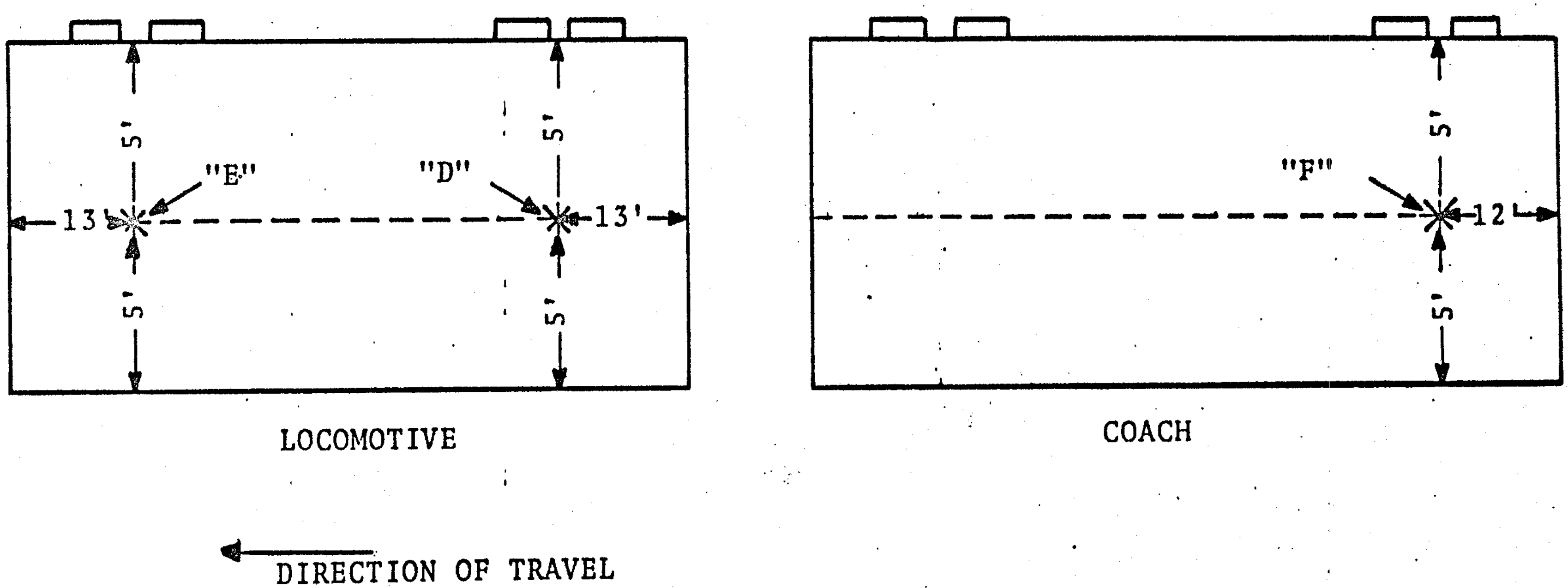


Figure 2. Position of Accelerometer Packages

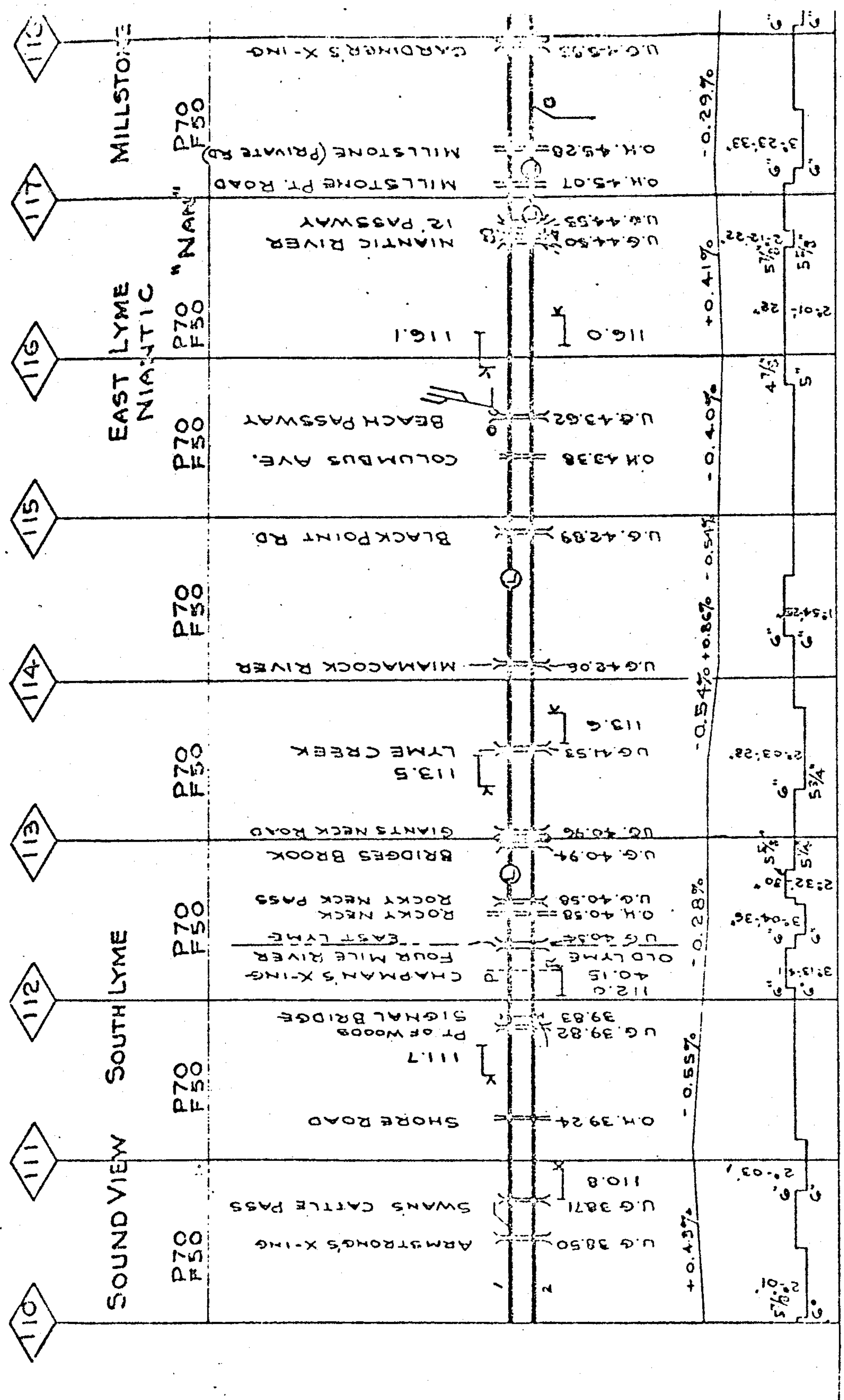
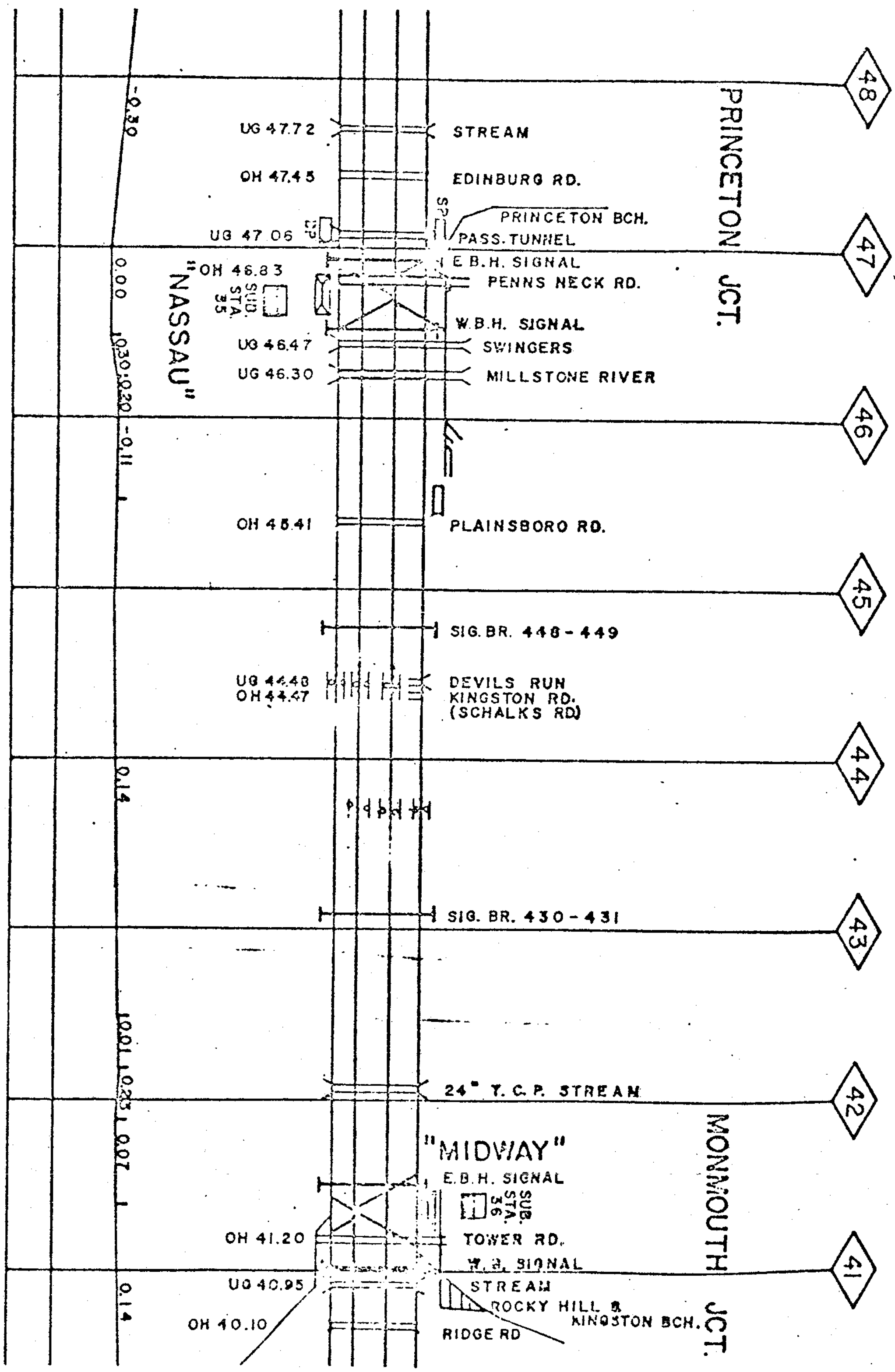

MILLSTONE
EAST LYME
NIANTIC
SOUTH LYME
SOUND VIEW
P70
F50
NIANTIC RIVER
BLACK POINT RD.
COLUMBUS AVE.
BEACH PASSWAY
MIAMACOCK RIVER
LYME CREEK
GIANTS NECK ROAD
BRIDGES BROOK
ROCKY NECK
ROCKY NECK PASS
FOUR MILE RIVER
SIGNAL BRIDGE
SHORE ROAD
SWANS CATTLE PASS
ARMSTRONG'S X-ING

Figure 3.

Figure 4.



48
47
46
45
44
43
42
41
PRINCETON JCT.
MONMOUTH JCT.
"NASSAU"
"MIDWAY"
UG 47.72
STREAM
OH 47.45
EDINBURG RD.
PRINCETON BCH.
UG 47 06
PASS. TUNNEL
E.B.H. SIGNAL
OH 46.83
PENNS NECK RD.
SUB. STA. 35
W.B.H. SIGNAL
UG 46.47
SWINGERS
UG 46.30
MILLSTONE RIVER
OH 45.41
PLAINSBORO RD.
SIG. BR. 448 - 449
UG 44.48
OH 44.47
DEVILS RUN
KINGSTON RD.
(SCHALKS RD)
SIG. BR. 430 - 431
24" T. C. P. STREAM
E.B.H. SIGNAL
SUB. STA. 36
OH 41.20
TOWER RD.
W.B. SIGNAL
UG 40.95
STREAM
ROCKY HILL & KINGSTON BCH.
OH 40.10
RIDGE RD
-0.30
0.00
0.30
0.20
-0.11
0.14
0.01
0.23
0.07
0.14

The runs completed for each phase of testing were as follows:

Test No.	Test Zone	Speed	Mode	Comment
1	Tangent	60	Power	
2	Tangent	70	Power	
3	Tangent	80	Power	
4	Tangent	90	Power	
5	Tangent	95	Power	
6	Tangent	80	Power	
7	Tangent	95	Power	
8	Tangent	100	Power	
9	Tangent	105	Power	
10	Tangent	110	Power	
11	Tangent	115	Power	
12	Tangent	120	Power	
13	Tangent	50	Drift	
14	Tangent	60	Drift	
15	Tangent	70	Drift	
16	Tangent	80	Drift	
17	Tangent	90	Drift	
18	Tangent	95	Drift	
1	Curved	54	Power	
2	Curved	42	Power	
3	Curved	58	Power	
4	Curved	53	Power	
5	Curved	42	Power	
6	Curved	60	Power	
7	Curved	61	Power	
8	Curved	71	Power	
9	Curved	73	Power	
10	Curved	75	Power	
11	Curved	82	Power	
12	Curved	80	Power	
13	Curved	90	Power	
14	Curved	87	Power	Banking Failure
15	Curved	75	Drift	
16	Curved	55	Drift	
17	Curved	67	Drift	
18	Curved	67	Dynamic Braking	
19	Curved	60	Dynamic Braking	

3.0 DATA REDUCTION

The first step taken in reducing the data collected on the LRC was to strip out data for each test section using a strip chart recorder. For the tangent zone, the area of track surrounding the perturbation zone was reproduced. For the curved zone, the entire curve was stripped out.

From these plots of raw data, several bits of data were extracted. First, the peak-to-peak lateral acceleration was determined for both the curved and tangent sections. Second, for the curved sections only, the centrifugal acceleration was measured.

Plots of the raw data for several of the high speed runs are included in Appendix D.

Next, the data for the curved zone was digitized at a 128 Hz rate on a RDS-500 mini-computer. A four-pole Bessel filter was used to low-pass filter the data at 20 Hz. Plots of the data were then generated from the digitized data. From this presentation of the raw data, the segments for data reduction were selected.

The data was reduced using a digital computer program. The output of the program includes:

- Standard Deviation (average RMS level)
- Probability Density Estimates and Plots
- Distribution Function Estimates and Plots
- RMS Acceleration Plots
- ISO Ride Evaluation Format
- Power Spectral Density Plots
- W_z Ride Criteria

A full description of the software techniques is included in Appendix C. Appendix E contains a sample printout from the software program.

4.0 RESULTS

Analysis of the test data was done using various analytical techniques. The data was initially filtered at 10 Hz using anti-aliasing filters and reproduced on strip charts. Vertical, lateral, and longitudinal accelerations were plotted as a function of time over the specified test zone for each of the three locations.

The data was then analyzed using the standard vehicle vibration software program. Results from this program include RMS level, 99 percentile level, W_z criteria and ISO exposure time.

4.1 Tangent Test Site

Runs were conducted over a perturbation in the track over the tangent test site. Because of the nature of this short term perturbation, software analysis was not felt to be useful in examining the results of these test runs. The data for each run was carefully reproduced on strip charts to determine the effect of the track perturbation on the dynamic acceleration levels of both the locomotive and coach.

Table 1 indicates the results for the tangent test site. The test run is indicated along with the test mode (power or drift). Both the target and actual speeds are given in miles per hour. The peak to peak lateral and vertical acceleration levels are recorded in this table at the time the vehicles crossed the perturbation in the track. These accelerations are measured in g's and are given for the leading and trailing trucks of the locomotive and the trailing truck of the coach. The maximum lateral load (in pounds) and the single wheel L/V, as measured by Battelle and Klauder (1), are also given in this table.

TABLE 1. TEST RESULTS - TANGENT ZONE

Test Run	Test Mode	Speed		Locomotive (Leading Truck)		Locomotive (Trailing Truck)		Coach (Trailing Truck)		Locomotive		Coach	
		Target	Actual	P-P Lat Accel (G's)	P-P Vert Accel (G's)	P-P Lat Accel (G-s)	P-P Vert Accel (G's)	P-P Lat Accel (G's)	P-P Vert Accel (G's)	Max Lat Load (lbs)	Single Wheel L/V	Max Lat Load (lbs)	Single Wheel L/V
1	Power	60	57	0.24	0.08	0.20	0.12	0.16	0.08	15,000	.48	4,000	.63
2	Power	70	69	0.26	0.10	0.29	0.16	0.20	0.08	18,000	.47	6,000	.44
3	Power	80	79	0.26	0.18	0.31	0.20	0.23	0.08	23,000	.77	10,000	.42
4	Power	90	89	0.28	0.14	0.30	0.20	0.26	0.08	22,000	.81	10,000	.27
5	Power	95	93	0.29	0.18	0.33	0.16	0.28	0.08	22,000	.81	10,000	.36
6	Power	80	77	0.29	0.22	0.32	0.24	0.23	0.08	23,000	.72	9,000	.54
7	Power	95	95	0.28	0.18	0.33	0.22	0.27	0.10	22,000	.81	13,000	.50
8	Power	100	99	0.29	0.18	0.32	0.22	0.28	0.10	24,000	.90	12,000	.50
9	Power	105	104	0.30	0.18	0.34	0.26	0.28	0.09	25,000	.83	12,000	.55
10	Power	110	108	0.31	0.20	0.34	0.28	0.28	0.10	25,000	.80	12,000	.72
11	Power	115	110	0.32	0.20	0.35	0.28	0.28	0.10	24,000	.72	12,000	.59
12	Power	115	117	0.32	0.20	0.34	0.26	0.29	0.14	26,000	.72	12,000	.64
13	Drift	50	52	0.20	0.10	0.18	0.08	0.14	0.08	18,000	.60	7,000	.36
14	Drift	60	58	0.24	0.10	0.21	0.08	0.20	0.08	17,000	.49	12,000	.45
15	Drift	70	69	0.28	0.12	0.30	0.14	0.20	0.08	19,000	.56	8,000	.55
16	Drift	80	78	0.30	0.16	0.29	0.24	0.26	0.08	22,000	.69	8,000	.64
17	Drift	90	87	0.30	0.16	0.29	0.18	0.26	0.09	21,000	.78	10,000	.55
18	Drift	95	92	0.30	0.14	0.30	0.18	0.28	0.09	21,000	.78	9,000	.82

In figure 5, the peak to peak lateral acceleration is plotted versus speed for the leading truck of the locomotive. The results for both the power and drift modes are compared. The results indicate that as speed increases the level of lateral acceleration increases. Acceleration levels tend to be slightly higher (4%) in the drift mode than in the power mode. Acceleration levels also tend to level out at speeds greater than 85 mph.

The equivalent graph for the trailing truck of the coach is given in figure 6. Again, lateral acceleration levels increase as speed increases and results in the drift mode are slightly higher than those in the power mode.

In figure 7, peak to peak lateral acceleration is plotted versus speed for the locomotive in a power mode. The levels of acceleration in the leading truck are compared against those in the trailing truck. The vehicle accelerations in the trailing truck are slightly higher than those in the leading truck. This might be attributed to the coach being coupled to that end.

Finally one can plot peak to peak lateral accelerations versus speed for a position over the trailing truck in the power mode. Acceleration levels in the locomotive are compared against those in the coach. The locomotive vibration levels are considerably higher than those in the coach, as would be expected. This plot is given in figure 8.

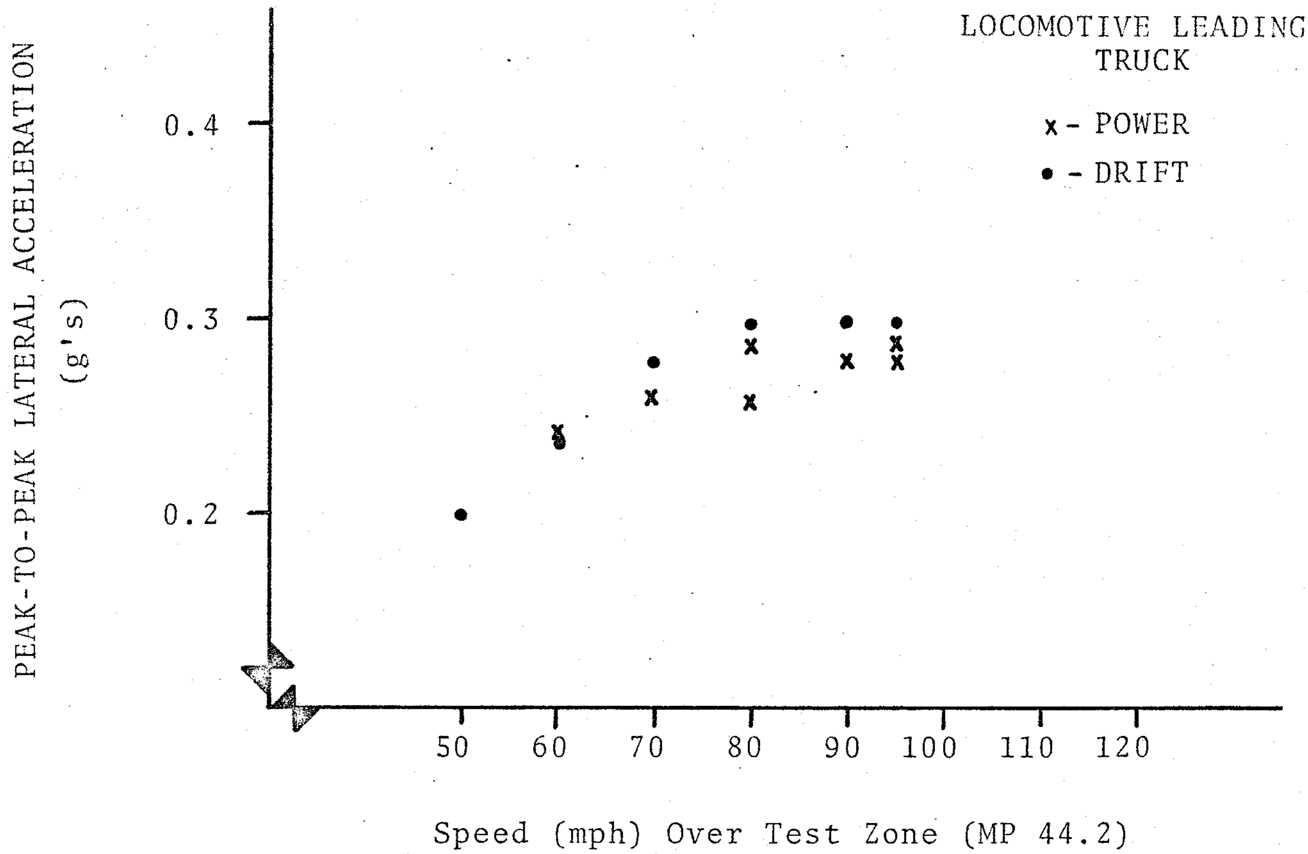


FIGURE 5

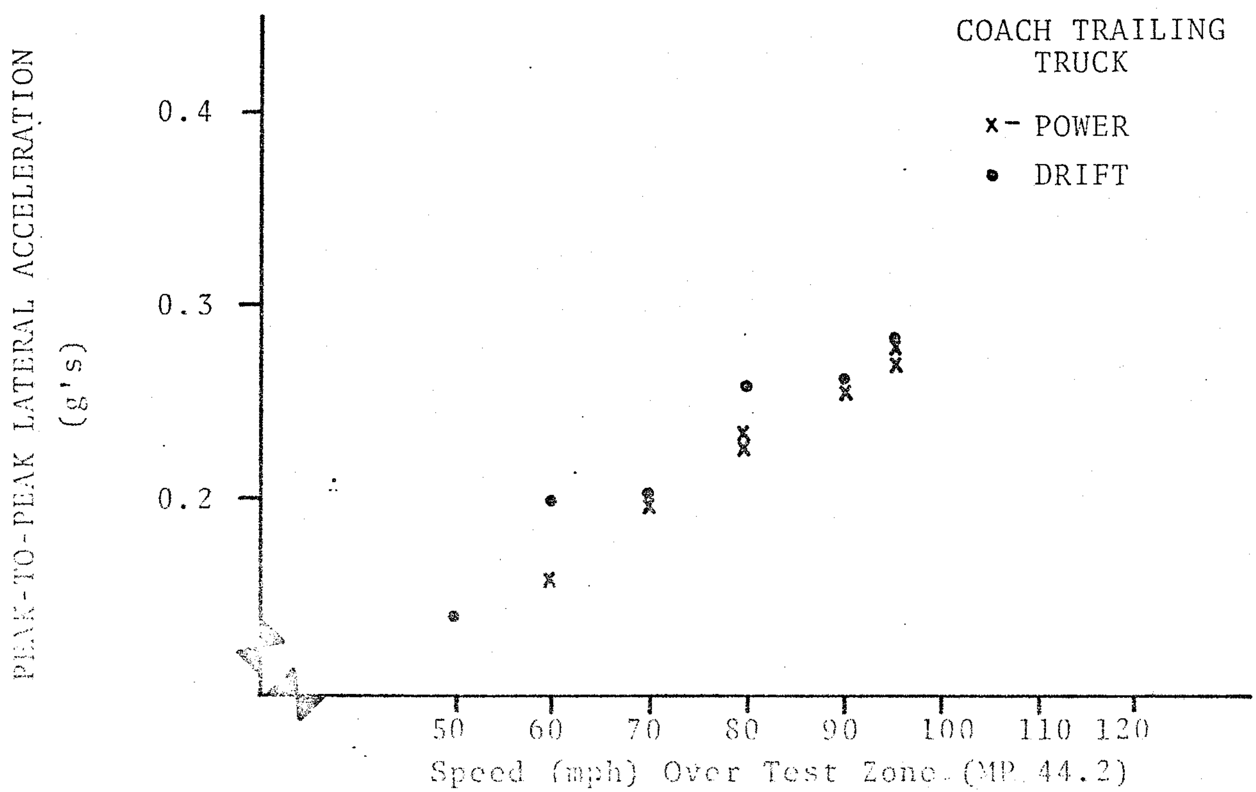


FIGURE 6

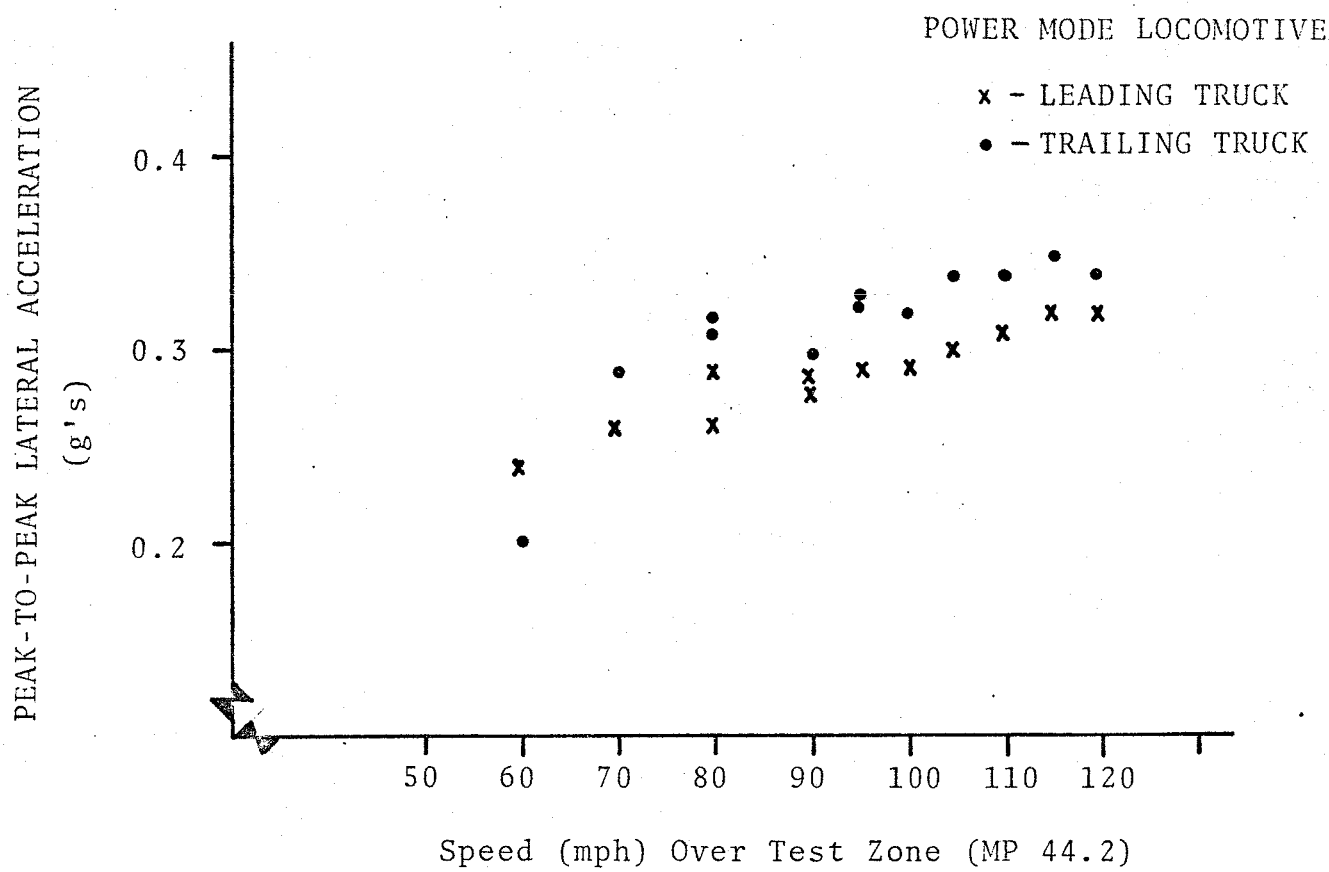


FIGURE 7

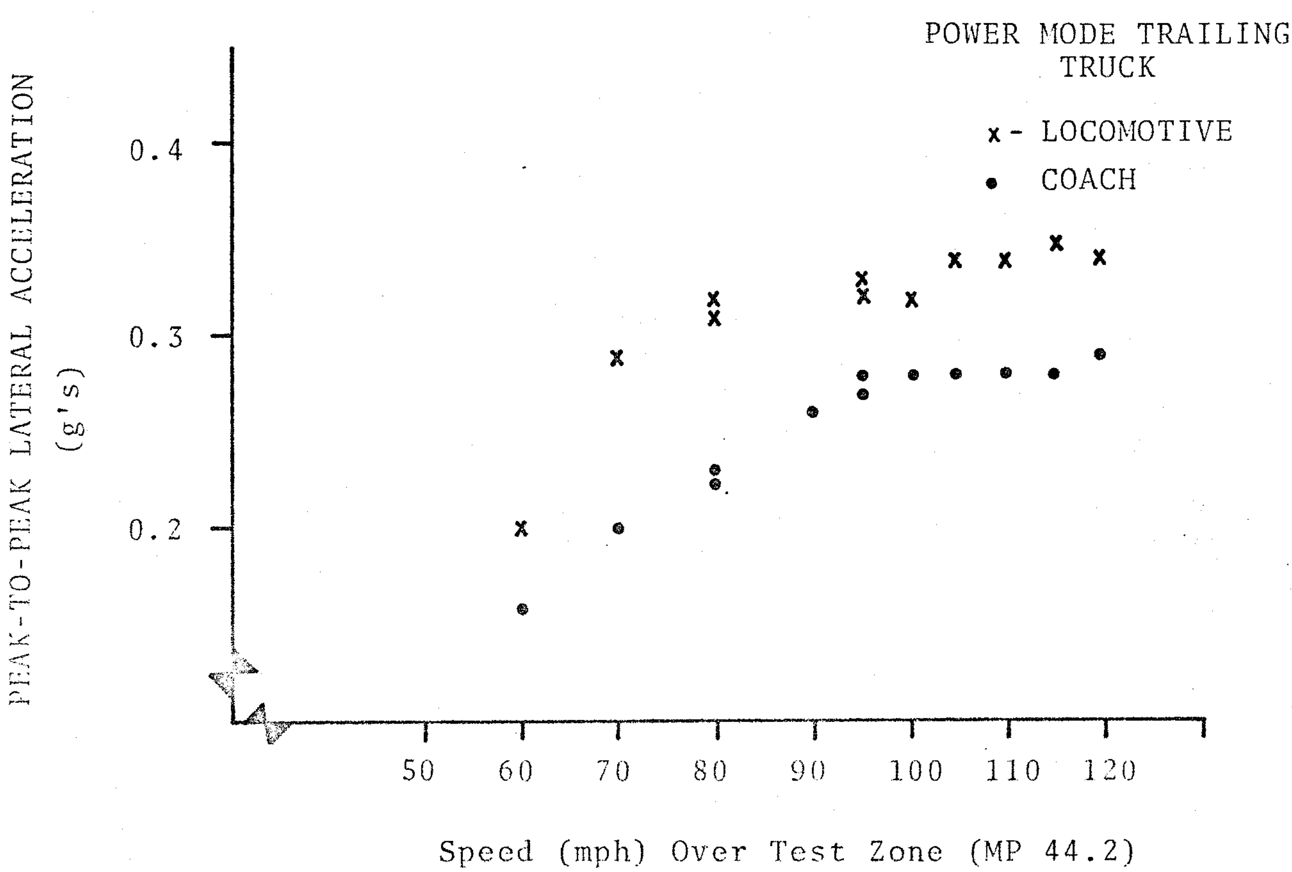


FIGURE 8

4.2 Curved Test Site

Data was collected on the curved track near East Lyme, CT in the same manner as the tangent zone. Data for each of the tests was initially reproduced on strip charts for preliminary examination and peak-to-peak lateral accelerations were extracted from these strip charts. In addition, the centripetal acceleration associated with the vehicles traversing the curved zone was also determined. These values are tabulated in Tables 2, 3, and 4.

From the wayside results [1], the maximum lateral load and single wheel L/V are also tabulated. The data was then analyzed using the standard vehicle vibration software package and the various results were again tabulated. These results include:

- Lateral RMS acceleration level
- Vertical RMS acceleration level
- Vertical 99% acceleration level
- Lateral 99% acceleration level
- Vertical W_z rating
- Lateral W_z rating
- Vertical ISO exposure time
- Lateral ISO exposure time

A complete description and explanation of these parameters can be found in Appendix C.

In examining the data, lateral rms acceleration is plotted against speed. This plot is shown in Figure 9. These results indicate no difference between the leading and trailing trucks of the LRC locomotive. The levels in the coach are substantially lower, as would be expected. In Figure 10, we plot the peak-to-peak lateral acceleration versus the speed over the test zone.

TABLE 2. TEST RESULTS: CURVED ZONE

TEST RUN	TEST MODE	SPEED		LRC LOCOMOTIVE (LEADING TRUCK)											
		TANGENT	ACTUAL	P-P LAT ACCEL (g's)	MAX LAT LOAD (lbs)	SINGLE L/V	LAT RMS (g's)	VERT RMS (g's)	99% LEVEL (VERT) g's	99% LEVEL (LAT)	W_z VERT	W_z LAT	ISO TIME VERT (hrs)	ISO TIME LAT (hrs)	CENT. ACC (g's)
1	Power	52	--	0.16	Void	--	0.022	0.043	0.118	0.069	2.6	2.3	4.6	5.4	0
2	Power	42	--	0.10	Void	--	0.018	0.041	0.106	0.052	2.6	2.1	4.4	5.4	.02
3	Power	60	61	0.16	16,000	0.41	0.026	0.046	0.140	0.080	2.7	2.4	4.6	4.3	.04
4	Power	52	56	0.16	16,000	0.40	0.023	0.043	0.118	0.073	2.6	2.3	4.5	5.2	0
5	Power	42	45	0.10	16,000	0.48	0.018	0.041	0.107	0.053	2.6	2.1	4.5	5.5	0
6	Power	63	65	0.18	17,000	0.41	0.028	0.046	0.140	0.082	2.7	2.4	4,7	3.3	.06
7	Power	67	64	0.20	16,000	0.38	0.029	0.048	0.145	0.083	2.7	2.5	4.3	2.6	.06
8	Power	73	72	0.20	21,000	0.47	0.034	0.053	0.149	0.085	2.8	2.6	2.6	1.8	.10
9	Power	76	73	0.18	21,000	0.47	0.035	0.053	0.167	0.086	2.8	2.6	2.9	2.0	.12
10	Power	76	75	0.17	26,000	0.53	0.036	0.047	0.122	0.087	2.7	2.7	4.5	1.9	.14
11	Power	79	83	0.26	27,000	0.55	0.042	0.061	0.203	0.113	2.9	2.8	3.3	1.5	.18
12	Power	79	79	0.22	24,000	--	0.040	0.058	0.183	0.106	2.9	2.7	3.0	1.6	.16
13	Power	87	90	0.30	38,000	0.52	0.048	0.060	0.203	0.127	2.9	3.0	3.4	1.3	.20
14	Power	86	84	0.24	30,000	0.44	0.047	0.060	0.188	0.125	2.9	2.9	3.0	1.5	.20
15	Drift	75	75	0.23	29,000	--	0.036	0.053	0.172	0.087	2.8	2.6	3.1	1.5	.13
16	Drift	52	55	0.18	18,000	--	0.025	0.043	0.123	0.076	2.6	2.3	4.9	3.7	0
17	Drift	67	67	0.20	20,000	0.44	0.032	0.051	0.147	0.080	2.8	2.5	3.3	2.6	.05

TABLE 3. TEST RESULTS: CURVED ZONE

TEST RUN	TEST MODE	SPEED		LRC LOCOMOTIVE (TRAILING TRUCK)									
		TANGENT	ACTUAL	P-P LAT ACCEL (g's)	LAT RMS (g's)	VERT RMS (g's)	99% LEVEL VERT (g's)	99% LEVEL LAT (g's)	W_z VERT	W_z LAT	ISO TIME VERT (hrs)	ISO TIME LAT (hrs)	CENT ACCEL (g's)
1	Power	52	--	0.16	0.022	0.039	0.104	0.064	2.5	2.2	6.6	6.6	0
2	Power	42	--	0.12	0.017	0.038	0.109	0.046	2.5	2.1	4.7	9.6	0
3	Power	60	61	0.10	0.028	0.033	0.088	0.075	2.4	2.4	6.7	3.2	0
4	Power	52	56	0.10	0.023	0.034	0.093	0.066	2.4	2.3	7.4	5.7	0
5	Power	42	45	0.10	0.016	0.040	0.111	0.047	2.5	2.0	5.7	8.4	0
6	Power	63	65	0.12	0.030	0.035	0.095	0.082	2.4	2.5	7.9	3.6	.06
7	Power	67	64	0.12	0.031	0.038	0.104	0.086	2.5	2.5	7.1	3.5	.06
8	Power	73	72	0.16	0.036	0.047	0.136	0.099	2.7	2.6	4.3	2.1	.10
9	Power	76	73	0.22	0.037	0.050	0.152	0.100	2.7	2.6	3.5	2.7	.12
10	Power	76	75	0.20	0.037	0.048	0.136	0.092	2.7	2.7	3.3	2.4	.14
11	Power	79	83	0.20	0.045	0.061	0.188	0.119	2.9	2.8	3.3	2.1	.18
12	Power	79	79	0.20	0.043	0.058	0.185	0.110	2.9	2.8	3.5	2.4	.16
13	Power	87	90	0.24	0.053	0.063	0.192	0.150	2.9	3.0	3.4	1.7	.26
14	Power	86	84	0.30	0.052	0.063	0.185	0.138	2.9	3.0	2.9	1.6	.24
15	Drift	75	75	0.23	0.039	0.048	0.149	0.104	2.7	2.7	3.8	1.9	.14
16	Drift	52	55	0.18	0.026	0.033	0.087	0.072	2.3	2.4	7.8	4.0	0
17	Drift	67	67	0.20	0.034	0.043	0.120	0.094	2.6	2.6	5.8	3.0	.05

TABLE 4. TEST RESULTS: CURVED ZONE

TEST RUN	TEST MODE	SPEED TANGENT	SPEED ACTUAL	LRC COACH (TRAILING TRUCK) P-P LAT ACCEL (g's)	MAX LAT LOAD (lbs)	SINGLE L/V	LAT RMS (g's)	VERT RMS (g's)	99% LEVEL VERT (g's)	99% LEVEL LAT (g's)	W_z VERT	W_z LAT	ISO TIME VERT (hrs)	ISO TIME LAT (hrs)	CENT. ACCEL (g)
1	Power	52	--	0.09	Void	Void	0.013	0.024	0.069	0.038	2.2	1.9	9.5	10.7	0
2	Power	42	--	0.05	Void	Void	0.010	0.022	0.057	0.028	2.1	1.8	10.0	16.9	0
3	Power	60	61	0.08	--	--	0.016	0.027	0.076	0.046	2.2	2.0	7.3	12.6	0
4	Power	52	56	0.07	--	--	0.014	0.024	0.065	0.039	2.2	1.9	10.5	15.6	0
5	Power	42	45	0.05	--	.50	0.009	0.020	0.054	0.026	2.0	1.7	13.3	19.1	0
6	Power	63	65	0.07	7,000	.41	0.016	0.025	0.069	0.043	2.2	2.0	8.0	10.7	0
7	Power	67	64	0.07	8,000	.47	0.019	0.029	0.083	0.059	2.3	2.1	7.7	10.5	0
8	Power	73	72	0.12	10,000	.67	0.023	0.030	0.085	0.069	2.3	2.2	7.6	6.9	0
9	Power	76	73	0.12	10,000	.45	0.023	0.031	0.089	0.065	2.3	2.3	7.3	5.3	.02
10	Power	76	75	0.12	9,000	.50	0.026	0.032	0.086	0.077	2.4	2.3	7.6	3.9	.02
11	Power	79	83	0.14	10,000	.43	0.030	0.034	0.092	0.086	2.4	2.4	7.3	3.2	.05
12	Power	79	79	0.14	8,000	--	0.030	0.034	0.089	0.086	2.4	2.4	7.5	3.3	.04
13	Power	87	90	0.19	11,000	.47	0.045	0.036	0.097	0.125	2.4	2.8	5.5	2.5	.15
14*	Power	86	84	0.16	10,000	.43	0.046	0.036	0.106	0.148	2.4	2.8	6.7	2.4	.30 Fail
15	Drift	75	75	0.16	8,000	--	0.027	0.032	0.090	0.069	2.4	2.3	6.8	5.1	0
16	Drift	52	55	0.13	6,000	--	0.015	0.030	0.085	0.048	2.3	1.9	6.4	11.7	0
17	Drift	67	67	0.16	8,000	.46	0.022	0.029	0.079	0.064	2.3	2.2	8.9	6.7	0

*Failure

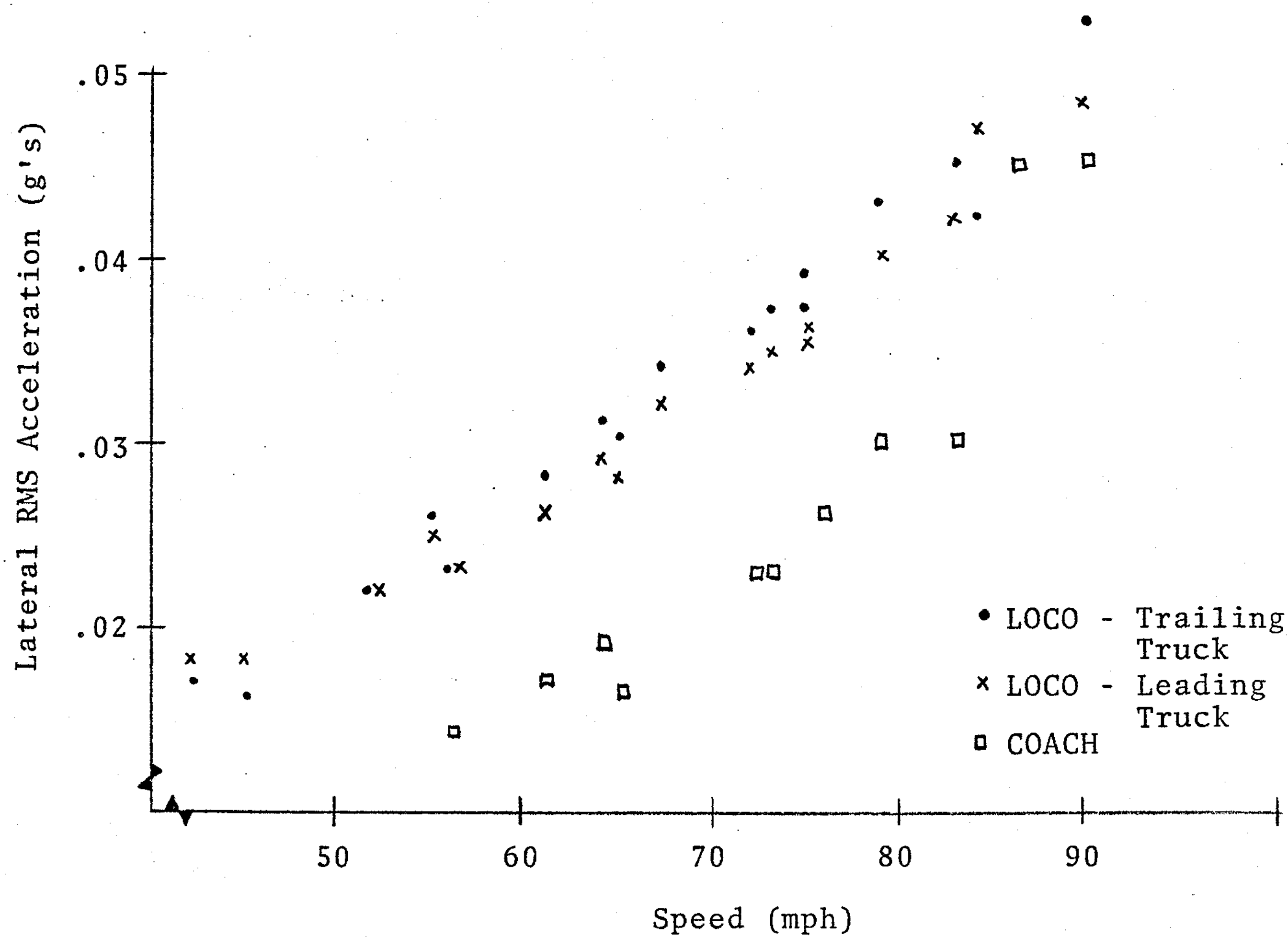


Figure 9. Lateral RMS Acceleration versus Speed

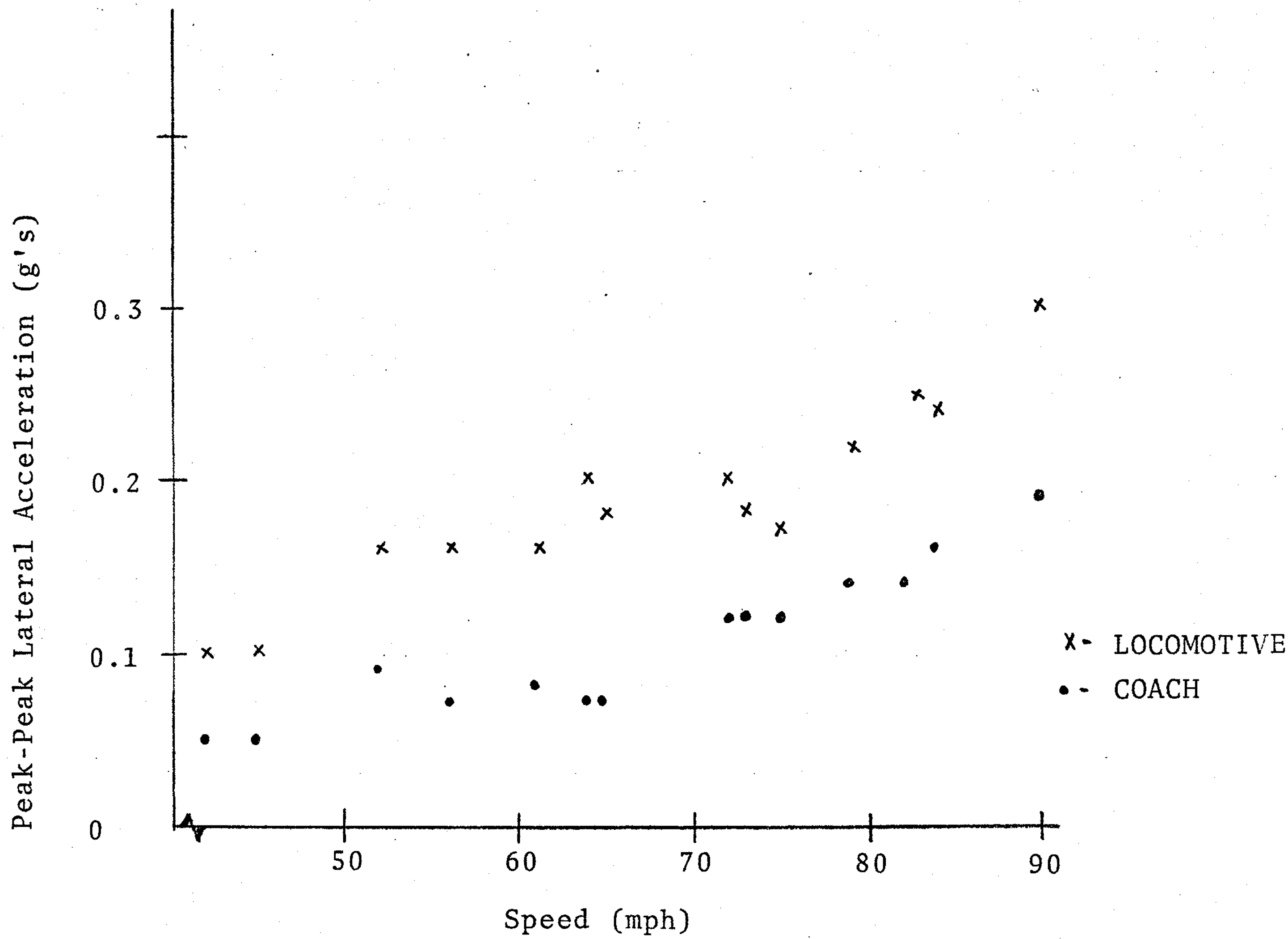


Figure 10. Peak-Peak Lateral Acceleration vs. Speed

Again it is seen that the levels of lateral acceleration increase with speed and that the levels of lateral acceleration associated with the coach are lower by a factor of 2 than those associated with the locomotive.

Next we would like to examine a significant event that occurred during testing on the curved zone. On Test #14, the banking system failed at a speed of 84 mph over the test zone. Although nothing serious resulted from this failure, personnel onboard the vehicle were thrown about the car. Figure 11 shows a trace of the lateral acceleration during this failure. At time equal to 0 seconds, the vehicle was performing as expected on the curve. During the next 3 seconds the system failed, which produced a 0.4 g jolt laterally in a time span of less than one second. Although not dangerous to the vehicle, this would be considered a very dangerous ride for passengers seated or standing within the vehicle during the failure. Even though the system failed as designed, it is felt that injuries would occur to passengers and steps should be taken to slow down the rate of deceleration during such a failure.

One important parameter in analyzing data collected on a curve is the centripetal acceleration sensed by the passengers. This acceleration level can be determined by examining the strip charts. These centripetal acceleration levels are tabulated in Tables 2, 3, and 4. Centripetal acceleration levels in the locomotive tend to increase above the balance speed of 52 mph. (The balance speed is defined as that speed at which no lateral force is experienced by the passenger).

Centripetal acceleration levels associated with the coach remain near zero up to 70 mph (due to the banking mechanism). At that point, those levels increase with speed but very slowly.

A simple model can be used to validate the data collected. Assuming the vehicle is on a elevated track, the outward

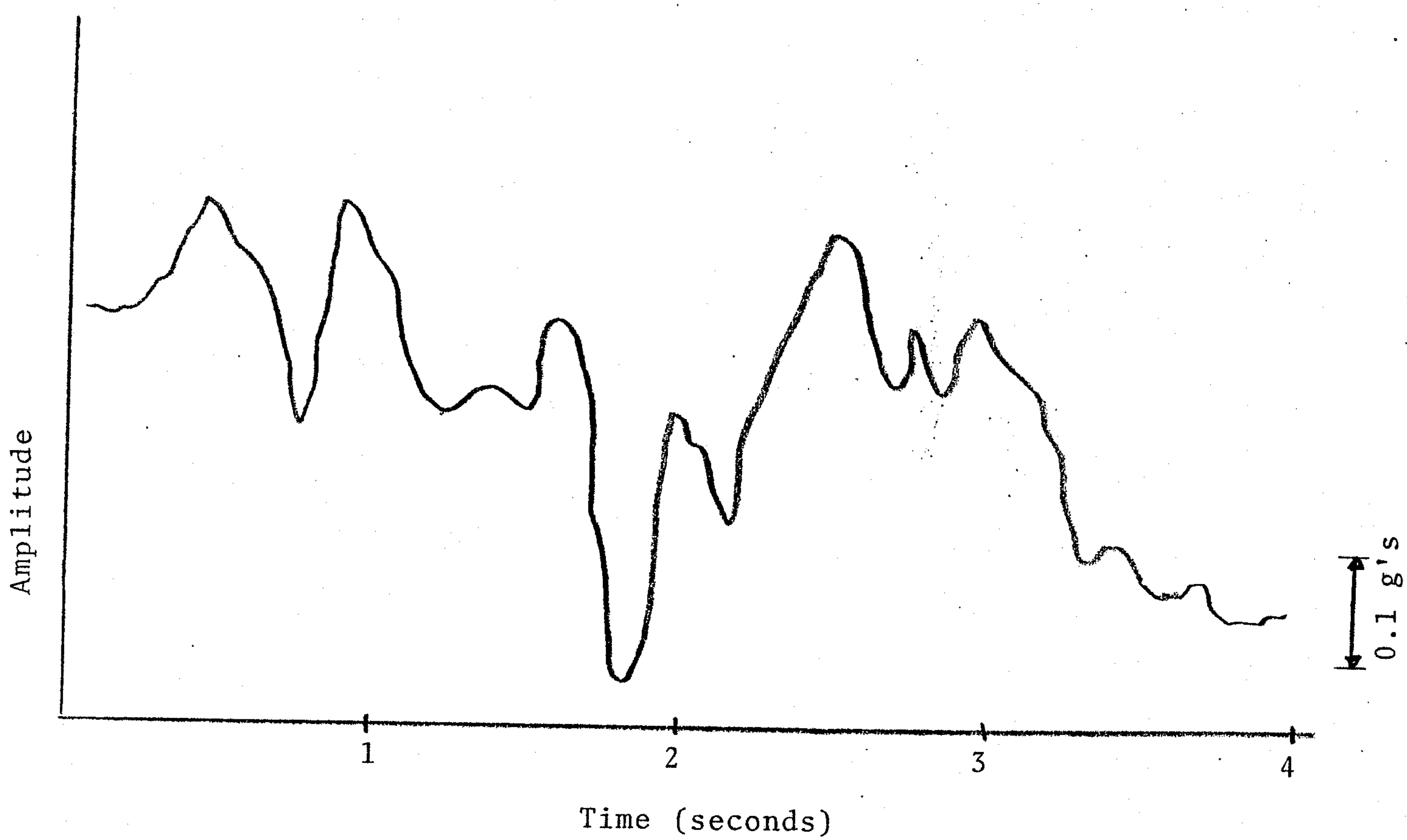


Figure 11. Acceleration of LRC coach during banking system failure

acceleration can be defined as:

$$a_{outward} = a_c \cos(\theta + \delta) - g \sin(\theta - \delta)$$

where

θ = superelevation of the track

a_c = the centripetal acceleration as seen on level track

$= V^2/R$

V = speed of vehicle

R = radius of curve

δ = angle associated with the spring system and mass distribution (0 on level track)

First, by using the simple model, one can determine the balance speed. At the balance speed, $a_{outward} = 0$. Then

$$a_c = V^2/R = g \sin(\theta - \delta)/\cos(\theta + \delta)$$

and

v is approximately 53 mph.

Figure 12 displays a plot of centripetal acceleration versus speed. On this graph, the following are plotted:

- locomotive results
- coach results
- theoretical rigid body results
- theoretical soft body results.

The result of this plot is that the simple model predicts very well the centripetal acceleration associated with the locomotive. The model does not account for the banking system of the coach.

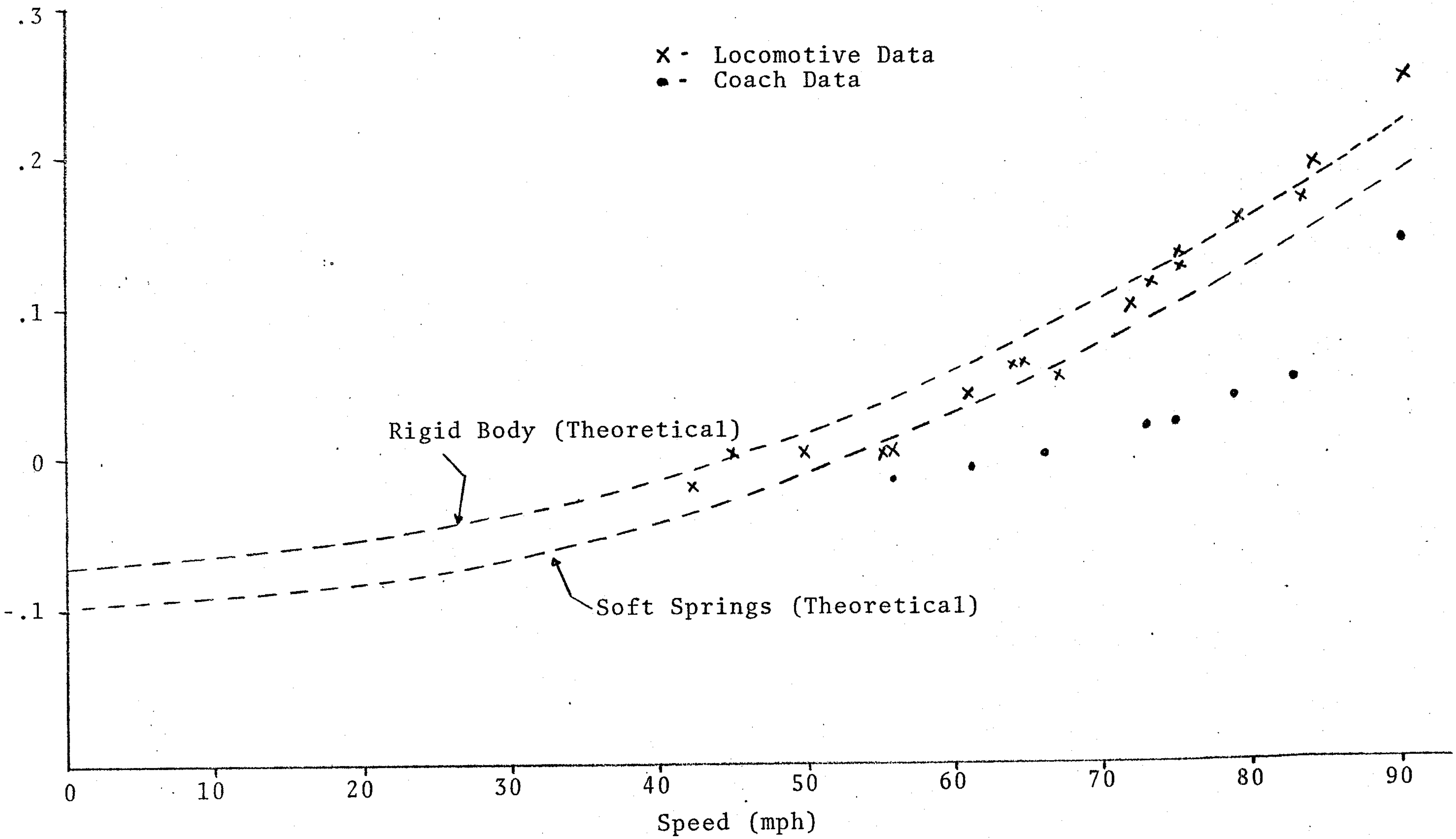


Figure 12. Centripetal Acceleration Levels

5.0 CONCLUSIONS

1) Examination of the data results associated with the banking failure creates a need for further evaluation of the banking system. Levels of acceleration within the vehicle along with a subjective description by onboard personnel indicates that serious injuries could occur to passengers if the banking system failed on a revenue run. Dangerous conditions with respect to the vehicle and track do not seem to exist.

2) On the tangent track, lateral acceleration levels tend to level off above 100 mph.

3) Over both test zones, the coach rides better than the locomotive by a factor of two, as defined by peak to peak and RMS accelerations.

4) Lateral accelerations tend to increase with speed for both the LRC coach and locomotive.

5) For the zones tested, the LRC coach provides a comfortable ride, as defined by RMS acceleration levels, ISO exposure times, and Wz rating.

6) The centripetal acceleration levels experienced by the LRC locomotive can be predicted by a simple mathematical model.

7) Centripetal acceleration levels in the LRC coach remain near zero up to speeds of 70 mph.

REFERENCES

[1] AMTRAK LRC Evaluation Tests, Klauder and Associates, January and March, 1977

APPENDIX A

TEST LOGS

TEST LOGS

The test logs are primarily designed as a check list to be used when setting up the instrumentation. The proper sequence for setting up the recorder and calibrating the accelerometers is given. The procedure for collecting the data is defined and the following information is requested:

1) Consist configuration
2) Personnel observing test
3) Position of accelerometers
4) Type of external signals recorded.

Messages are then recorded with respect to speed, milepost, points of reference, and any other details that will help identify that portion of the test. These messages are recorded directly on the analog tape and are very helpful in processing the data at a later time.

DATE 31-23 Mar 77
TIME
OPERATOR J. Adair
J. Berglund

PORTABLE RIDE QUALITY PACKAGE
USER CHECK LIST

Milepost 44.2
Tangent

1. Initial set up - check out

[X] a. Ensure that the record amplifier boards are inserted with proper filters in their respective positions in the tape recorder. FM record boards are located in channels 1 through 6. A direct record board is placed in channel 7. Rep 1/SW remains the same.

[X] b. Tape speed is 1 7/8 ips. Make sure tape is threaded properly and tape is useable.

[X] c. Connect all cables. Plug in 115v AC line if battery is not used.

[X] d. Check if battery is fully charged by pressing Batt on recorder. Indiator should show a value to the + side of 0. Make sure recorder is on.

[X] e. Press 7 on recorder. Indicator should be close to zero. This shows that direct record channels are working properly.

[X] f. Switch monitor function to ±15v and ±7 1/2v. Reading should be full scale on all four locations. If reading is not full scale, internal problems exist or battery is dead.

[X] g. Set up accelerometers in place using directional axis located on instrumentation.

[X] h. Reset message number to 0. Turn memory on. Enable display, when pressed, will display the present message unit.

2. Initial test. After each and every re-location of the Accelerometer package an operational check of each channel must be performed. This can be accomplished by the following procedure:

a. Activate "Record" and "Play" buttons on the tape recorder.

b. Select the particular channel to be checked on the monitor function switch (roll, pitch, etc.).

c. Physically rotate the Accelerometer package in the particular axis being tested and observe any fluctuations on the signal monitor. If there are fluctuations present, the Accelerometer package is operating properly for that axis.

d. Repeat steps (2) and (3) for each channel.

1	2	3	4	5	6
X	X	X	X	X	X
Roll	Pitch	Yaw	Vert.	Long.	Lat.

3. Calibration

a. Switch recorder on (record, play). Record test ID, i.e., test number, date, location, purpose, etc., on voice channel. Enter message unit 1.

b. Position the SW/reporduce channel selector on the tape recorder to the channel to be calibrated (#1, #2, etc.)

c. Position the monitor function switch to the specific channel to be calibrated (roll, pitch, etc.) Update message number. Message numbers 2 through 7 should indicate calibration signal. Use voice channel to record what accelerometers are being calibrated, etc.

d. Press the calibration switch to +cal, hold for 3 seconds, switch to - cal, hold for one second, then release.

e. Repeat this procedure for all six channels until all calibration signals are recorded.

1	2	3	4	5	6
X	X	X	X	X	X
Roll	Pitch	Yaw	Vert.	Long.	Lat.

f. Unit is now ready to collect data.

4. Data Collection

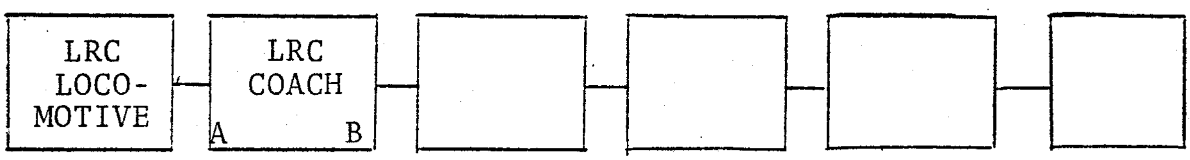
a. Activate "Record" and "Play" buttons on the tape recorder. Enter message number for beginning of test data.

b. Enter additional message numbers, vocal comments, etc., for points of interest, milepost numbers, speed, etc.

c. One can visually monitor the accelerations. By selecting the appropriate channel on the monitor function switch, the output will be displayed on the signal monitor. In addition, by switching the position of the SW/reproduce channel selector on the tape recorder, the output is displayed on the SW/reproduce channel meter. A scale factor of 10 can be activated to produce a more sensitive reading.

d. When the data is fully collected, turn recorder off. After disengaging cables, turn off memory and pack up unit.

CONSIST



PERSONNEL PRESENT:

R. Watson	Klauder
J. Jackson	AMTRAK
G. Merakus	AMTRAK
E. Conner	AMTRAK
D. Boria	AMTRAK
E. Barbeau	MLW

J. Berglund J. Adair	ENSCO
W. Bennett E. Lombardi	AMTRAK
R. Scharr A. Lampros	FRA
F. Blader R. Johnson	Nat. Res. Council B. Northern
R. Robillard C. Mainville	MLW
W. McLean J. Layton	MLW JL1 Industries

POSITION OF PACKAGE:

"D" Rear Truck, Loco, Truck Center

"E" Front Truck, Loco, Truck Center
"F" Rear Truck, Coach

B Recorder - Coach (J1)
C Recorder - Locomotive
J1 - Front
J2 - Rear

Train Speed #1

Banking Displacement #2

MESSAGES

1.	Calibration	28.	75 mph
2.	Speed Cal (Voice)	29.	MP63
3.	-	30.	-
4.	-	31.	MP61
5.	65 mph	32.	-
6.	69 mph	33.	End of Test
7.	70 mph	34.	Calibration
8.	72 mph	35.	-
9.	75 mph	36.	-
10.	M77 Track #2	37.	Start #1 60-Power
11.	77 mph	38.	-
12.	78 mph	39.	Approach Zone
13.	MP75 78 mph	40.	Test Zone
14.	MP74	41.	Stop #1
15.	MP73 79 mph	42.	Start #2 70-Power
16.	79 mph	43	-
17.	MP72	44.	Approach Zone
18.	75 mph	45.	Test Zone
19.	MP71	46.	Stop #2
20.	78 mph	47.	Start #3 80 mph-Power
21.	-	48.	-
22.	MP69	49.	-
23.	MP68 67 mph	50.	Approach Zone
24.	MP67	51.	Test Zone
25.	63 mph	52.	Stop #3
26.	—	53.	Start #4 90-Power
27.	MP65	54.	-

MESSAGES

55. -
56. -
57. Approach Zone
58. Test Zone
59. Stop #4
60. Start #5 95-Power
61. -
62. -
63. -
64. Approach Zone
65. Test Zone
66. Stop #5
67. Calibration
68. Speed Cal.
69. Speed Cal.
70. Speed Cal.
71. Speed Cal.
72. Speed Cal.
73. Speed Cal.
74. Speed Cal.
75. Speed Cal.
76. Speed Cal.
77. Start #6 80-Power
78. -
79. -
80. -
81. -
82. Approach Zone
83. Test Zone
84. Stop #6
85. Start #7 95-Power
86. -
87. -
88. Approach Zone
89. Test Zone
90. End #7
91. Start #8 100-Power
92. -
93. -
94. Approach Zone
95. Test Zone
96. Stop #8
97. Start #9 105-Power
98. -
99. -
100. -
101 -
102. -
103. -
104. Approach Zone
105. Test Zone
106. Stop #9
107. Start #10 110-Power
108. -

MESSAGES

109. -
110. -
111. Approach Zone
112. Test Zone
113. Stop #10
114. Start #11 115-Power
115. -
116. -
117. -
118. Approach Zone
119. Test Zone
120. Stop #11
121. Start #12 120-Power
122. -
123. -
124. -
125. -
126. -
127. -
128. -
129. Approach Zone
130. Test Zone
131. Stop #12
132. Start #13 50-Drift
133. Approach Zone
134. Test Zone
135. Stop #13
136. Start #14 60 mph
137. -
138. Approach Zone
139. Test Zone
140. Stop #14
141. Start #15 70-Drift
142. Approach Zone
143. Test Zone
144. Stop #15
145. Start #16 80-Drift
146. -
147. -
148. Test Zone
149. Stop #16
150. Start #17 90-Drift
151. -
152. -
153. -
154. Approach Zone
155. Test Zone
156. End #17
157. Start #18 95-Drift
158. -
159. -
160. Approach Zone
161. End #18
162.

DATE 29 March 77

TIME

OPERATOR J. Adair
J. Berglund

PORTABLE RIDE QUALITY PACKAGE
USER CHECK LIST

1. Initial set up - check out

[X] a. Ensure that the record amplifier boards are inserted with proper filters in their respective positions in the tape recorder. FM record boards are located in channels 1 through 6. A direct record board is placed in channel 7. Rep 1/SW remains the same.

[X] b. Tape speed is 1 7/8 ips. Make sure tape is threaded properly and tape is useable.

[X] c. Connect all cables. Plug in 115v AC line if battery is not used.

[X] d. Check if battery is fully charged by pressing Batt on recorder. Indiator should show a value to the + side of 0. Make sure recorder is on.

[X] e. Press 7 on recorder. Indicator should be close to zero. This shows that direct record channels are working properly.

[X] f. Switch monitor function to ±15v and ±7 1/2v. Reading should be full scale on all four locations. If reading is not full scale, internal problems exist or battery is dead.

[X] g. Set up accelerometers in place using directional axis located on instrumentation.

[X] h. Reset message number to 0. Turn memory on. Enable display, when pressed, will display the present message unit.

2. Initial test. After each and every re-location of the Accelerometer package an operational check of each channel must be performed. This can be accomplished by the following procedure:

   a. Activate "Record" and "Play" buttons on the tape recorder.

   b. Select the particular channel to be checked on the monitor function switch (roll, pitch, etc.).

c. Physically rotate the Accelerometer package in the particular axis being tested and observe any fluctuations on the signal monitor. If there are fluctuations present, the Accelerometer package is operating properly for that axis.

d. Repeat steps (2) and (3) for each channel.

1	2	3	4	5	6
X	X	X	X	X	X
Roll	Pitch	Yaw	Vert.	Long.	Lat.

3. Calibration

a. Switch recorder on (record, play). Record test ID, i.e., test number, date, location, purpose, etc., on voice channel. Enter message unit 1.

b. Position the SW/reporduce channel selector on the tape recorder to the channel to be calibrated (#1, #2, etc.)

c. Position the monitor function switch to the specific channel to be calibrated (roll, pitch, etc.) Update message number. Message numbers 2 through 7 should indicate calibration signal. Use voice channel to record what accelerometers are being calibrated, etc.

d. Press the calibration switch to +cal, hold for 3 seconds, switch to - cal, hold for one second, then release.

e. Repeat this procedure for all six channels until all calibration signals are recorded.

1	2	3	4	5	6
X	X	X	X	X	X
Roll	Pitch	Yaw	Vert.	Long.	Lat.

f. Unit is now ready to collect data.

4. Data Collection

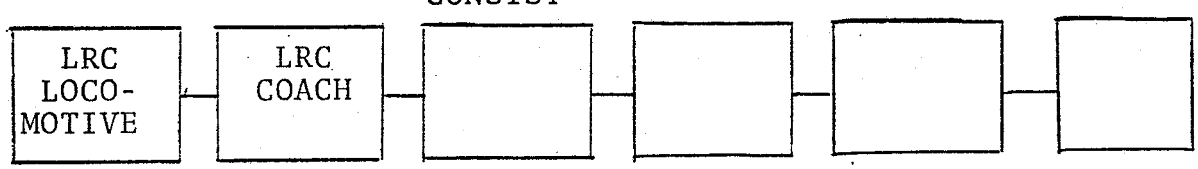
a. Activate "Record" and "Play" buttons on the tape recorder. Enter message number for beginning of test data.

b. Enter additional message numbers, vocal comments, etc., for points of interest, milepost numbers, speed, etc.

c. One can visually monitor the accelerations. By selecting the appropriate channel on the monitor function switch, the output will be displayed on the signal monitor. In addition, by switching the position of the SW/reproduce channel selector on the tape recorder, the output is displayed on the SW/reproduce channel meter. A scale factor of 10 can be activated to produce a more sensitive reading.

d. When the data is fully collected, turn recorder off. After disengaging cables, turn off memory and pack up unit.

CONSIST



PERSONNEL PRESENT: See Tangent Test Logs

POSITION OF PACKAGE: See Tangent Test Logs

MESSAGES

1.	Calibration C-Unit Coach	28.	MP112
2.	- B-Unit Loco	29.	Test Site (42 mph Power)
3.	Speed/LVDT Signal	30.	End Zone
4.	Start Data Enroute	31.	Start Test #3 (60 mph-Power)
5.	-	32.	-
6.	40 mph	33.	MP112
7.	57 mph	34.	Test Site (58 mph)
8.	64 mph	35.	End of Test
9.	Stop	36.	Start Test #4 (52-Power)
10.	Start 81 mph	37.	-
11.	85 mph	38.	MP112
12.	85 mph	39.	-
13.	MP89	40.	Test Site 53-mph
14.	MP91	41.	End of Test
15.	Stop	42.	Start Test #5 42-Power
16.	Test #1 52 mph Power	43	-
17.	MP108	44.	MP112
18.	70 mph	45.	Test Site (42 mph)
19.	-	46.	End of Test
20.	-	47.	Start Test #6 63-Power
21.	-	48.	-
22.	MP112	49.	-
23.	Test Site (54 mph)	50.	MP112
24.	End of Test	51.	Test Site (60 mph)
25.	Start #2 42 mph Power	52.	End Test
26.	-	53.	-
27.	-	54.	-

MESSAGES

55. Start Test #7
56. -
57. MP112
58. Test Site (61 mph)
59. End Test
60. Start Test #8 (73 power)
61. 65 mph
62. -
63. MP112
64. Test Site (71 mph)
65. End of Test
66. Start Test #9 (86 Power)
67. -
68. MP112
69. Test Site (73 mph)
70. End Test
71. Start Test #10 (76 Power)
72. -
73. MP112
74. Test Site (75 mph)
75. End Test
76. Start Test #11 (79 Power)
77. -
78. MP112
79. Test Site (82 mph)
80. End Test
81. Start Test #12
82. -
83. MP112
84. Test Site (80 mph)
85. End of Test
86. Start Test #13 (87 Power)
87. -
88. MP112
89. Test Site (90 mph)
90. End of Test
91. Start Test #14 (87 Power)
92. MP112
93. Test Site (87) Banking Failure
94. End of Test
95. Stop
96. Calibration
97. Calibration
98. Calibration
99. Start Test #15 (75 Drift)
100. -
101. MP112
102. Test Site (73 mph)
103. End Test
104. Start Test #16 (52 Drift)
105. -
106. MP112
107. Test Site (55 mph)
108. End Test

MESSAGES

109. Start Test #17 (67 Drift)
110. -
111. MP112
112. Test Site (67 mph)
113. End of Test
114. Start Test #18 (67 dB)
115. -
116. MP112
117. Test Site (75-65 mph)
118. End Test
119. Start Test #19 (60 Dynamic)
120. -
121. MP112
122. Test Site
123. End Test
124. Calibration
125. Calibration
126.
127.
128.
129.
130.
131.
132.
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134.
135.
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APPENDIX B

INSTRUMENTATION HARDWARE

INSTRUMENTATION HARDWARE

The ride quality of a vehicle is evaluated from acceleration data. The data consist of vehicle vibrations that are recorded in analog form. The data collection system primarily used is the FRA/ENSCO portable ride quality package (See Figure B-1). Data is recorded using six accelerometers. Depending upon the requirements of the test, either six linear accelerometers or three linear and three angular accelerometers are used. Figure B-2 gives the relationship of the measurement areas.

This data collection system consists of a magnetic tape recorder, a signal conditioning and coding unit, and an accelerometer package. The accelerometer package details can be found in Table B-1. The signal 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 sign signals, an internally generated digital annotation, and a reference signal. A channel is provided for voice annotation.

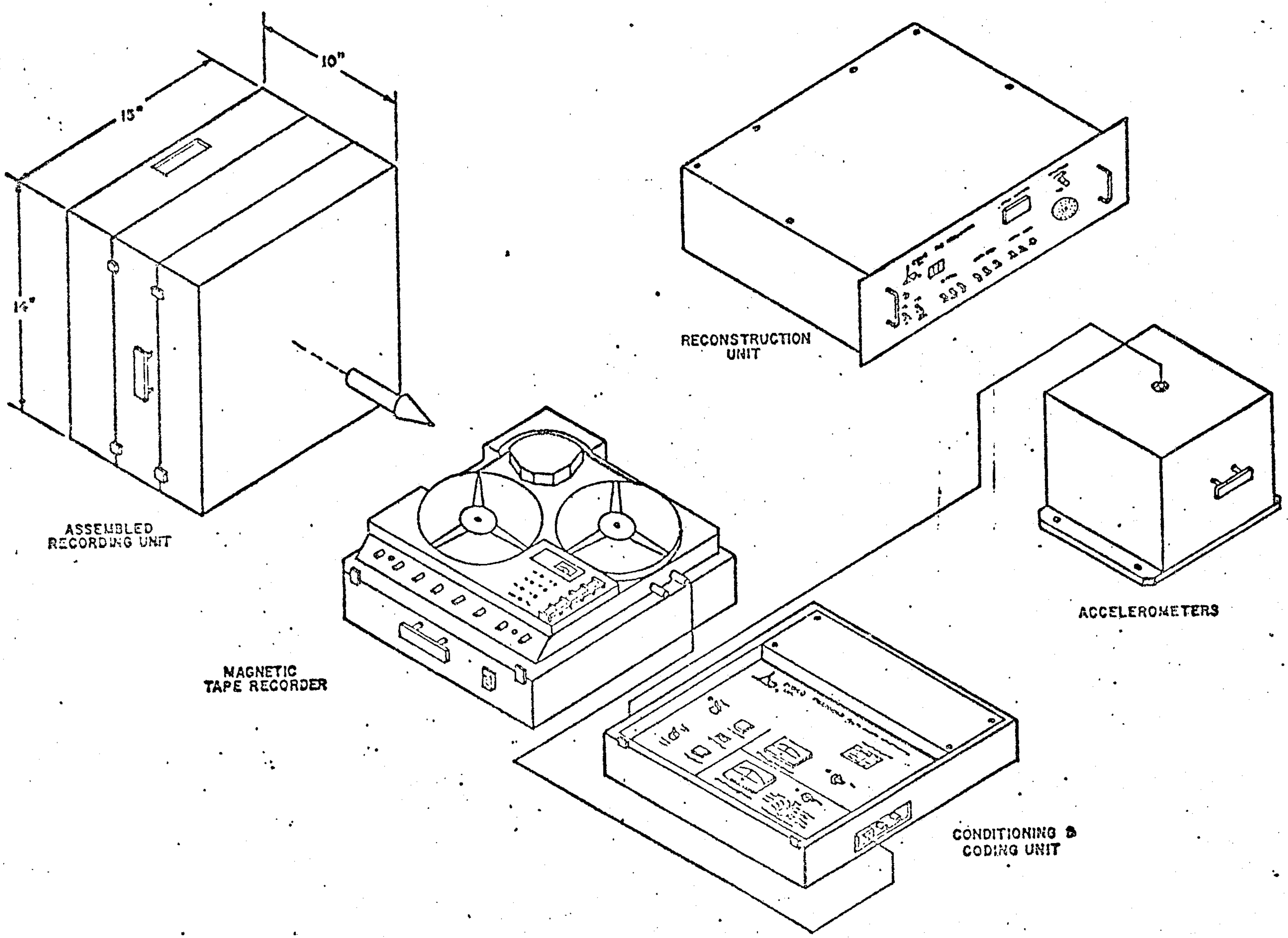


Figure B-1. Portable Ride Quality Package

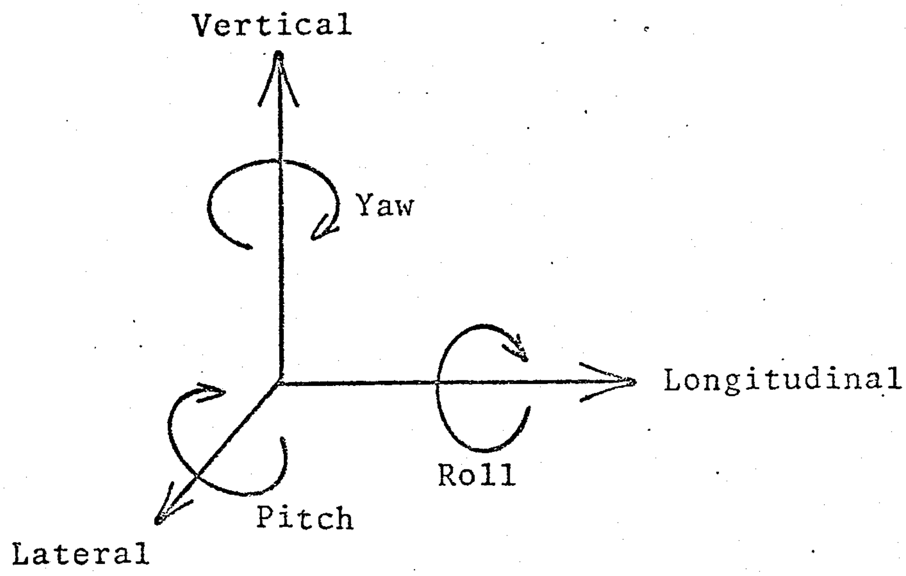


Figure B-2. Relationship of Measurement Axes

Table B-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

In the past, ENSCO had the capability of collecting vehicle vibration data using a six-axis accelerometer package. This package provided translational and angular information concerning the motion of the vehicle. Each of the two packages was complete 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 is that data can only be collected at one location in the vehicle. A second recorder must be used to collect data in two locations either within the vehicle or in two separate vehicles. Additional manpower is also necessary to use a second recording system. A second disadvantage is that the angular accelerometers require more maintenance than the linear ones and are more difficult to examine. Table B-2 indicates our past ride quality instrumentation capabilities. Figure B-3 illustrates package 1 or 2.

Table B-2. Previous Instrumentation Capabilities

System 1:	"B" Tape Recorder "B" Coding Unit "B" 6-Axis Accelerometers -is able to collect 6 channels (3 linear and 3 angular) at one location.
System 2:	"C" Tape Recorder "C" Coding Unit "C" 6-Axis Accelerometers -is able to collect 6 channels (3 linear and 3 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 separates the signals. Table B-3 summarizes the expanded capabilities gained by using a junction box. Figure B-4 illustrates this system.

Figure B-3. System 1 or 2

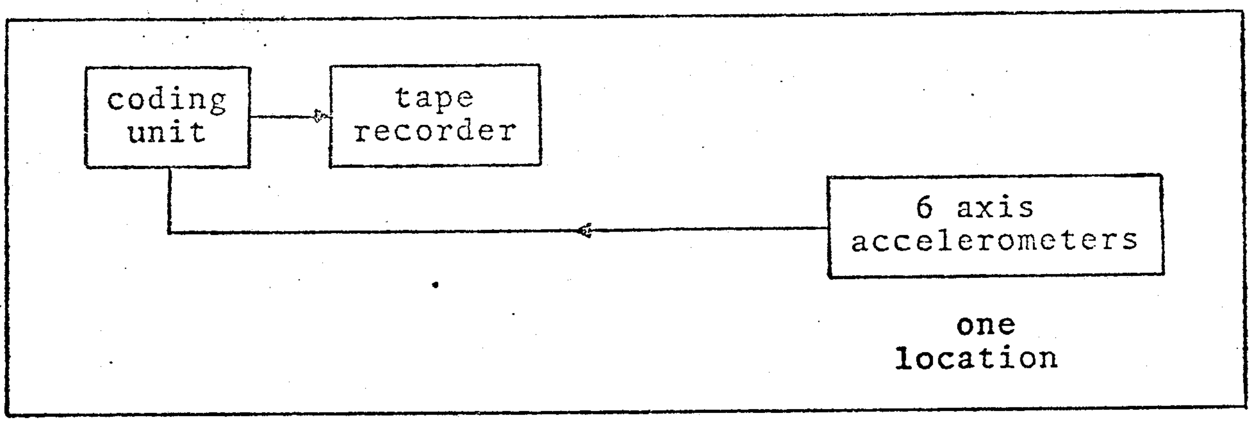
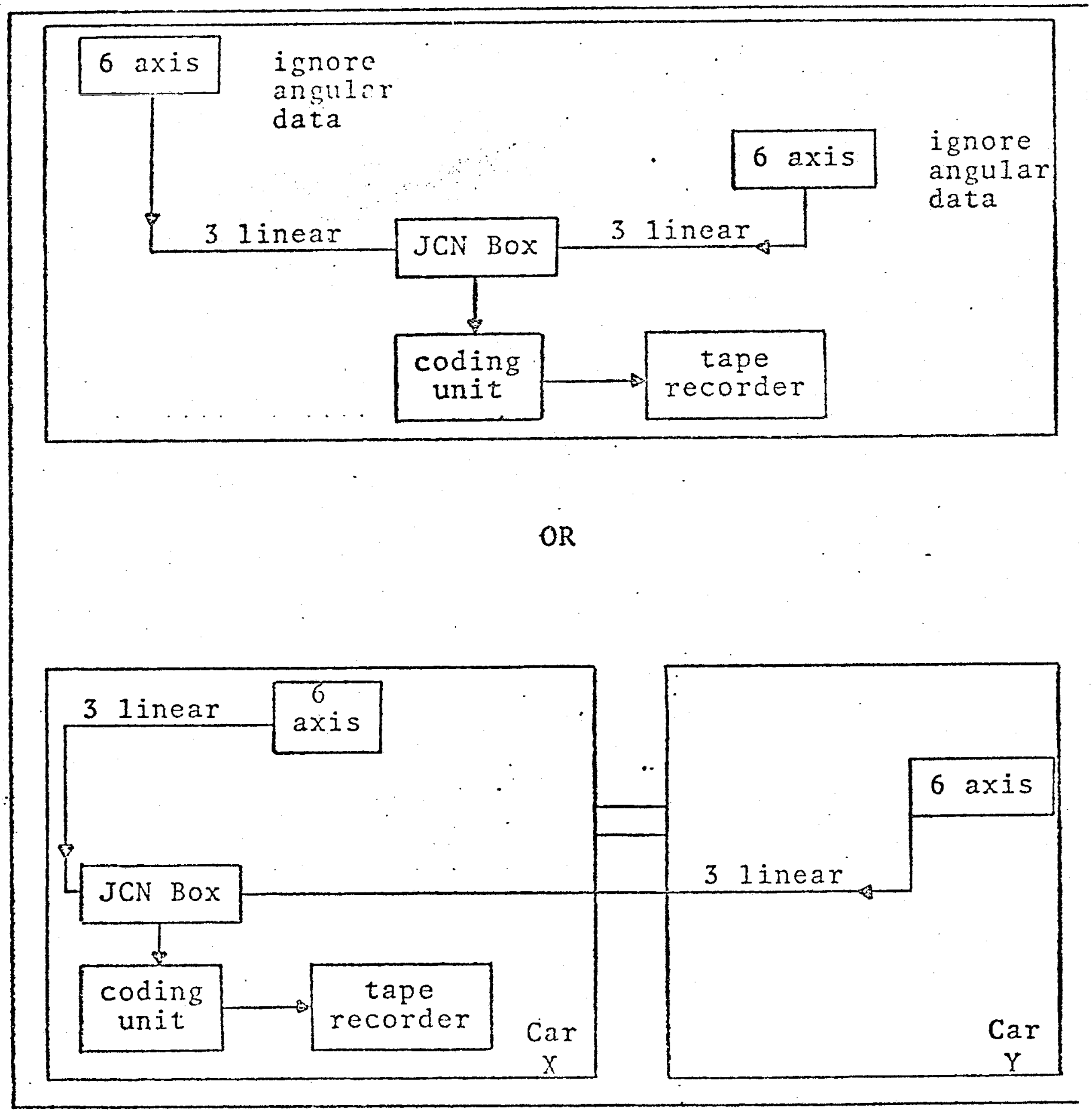


Table B-3. Additional Capabilities

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 B-4. System 3 Capabilities



Although System 3 is a more efficient system, it still required the use of 2 bulky accelerometer systems, each containing 3 angular accelerometers not being used.

To provide a better system, a set of three (1 back-up) tri-axial accelerometer systems was built. Each tri-axial package contains 3 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 B-4 defines the various configurations that can presently be used in collecting data.

The present inventory of ride quality instrumentation includes the following:

(3) Tape Recorders
(2) Coding Units
(2) 6-Axis Accelerometer Systems
(3) Tri-Axis Accelerometer Systems
(2) Cables 30 feet long
(4) 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 B-5 should be used when selecting test instrumentation. All the instrumentation is interchangeable and requires no additional calibration.

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 B-4. Various Potential Configurations

Table B-5. Selection of Instrumentation

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

APPENDIX C

SOFTWARE DESCRIPTION

SOFTWARE DESCRIPTION

1.1 INTRODUCTION

At the heart of the software processing is a RDS-500 computer which has the capability of processing any type of vehicle vibration data. Figure C-1 is a diagram of the ENSCO RDS-500 configuration.

The processing produces two types of results: time series results and frequency dependent results. The time series results include the following:

- Probability Density Estimate
- Distribution Function Estimate
- RMS Acceleration Level
- Average RMS Level
- 99 and 95 Percentile Levels

The frequency dependent results include the following:

- Average RMS levels for 1/3 octave bands
- ISO reduced comfort exposure times
- Power Spectral Densities
- Alternate ISO exposure times
- Cepstrum plots of power spectra
- W_z criteria

A more complete discussion of the time series results can be found in Appendix E. A description of the ISO and W_z criteria is included in this appendix.

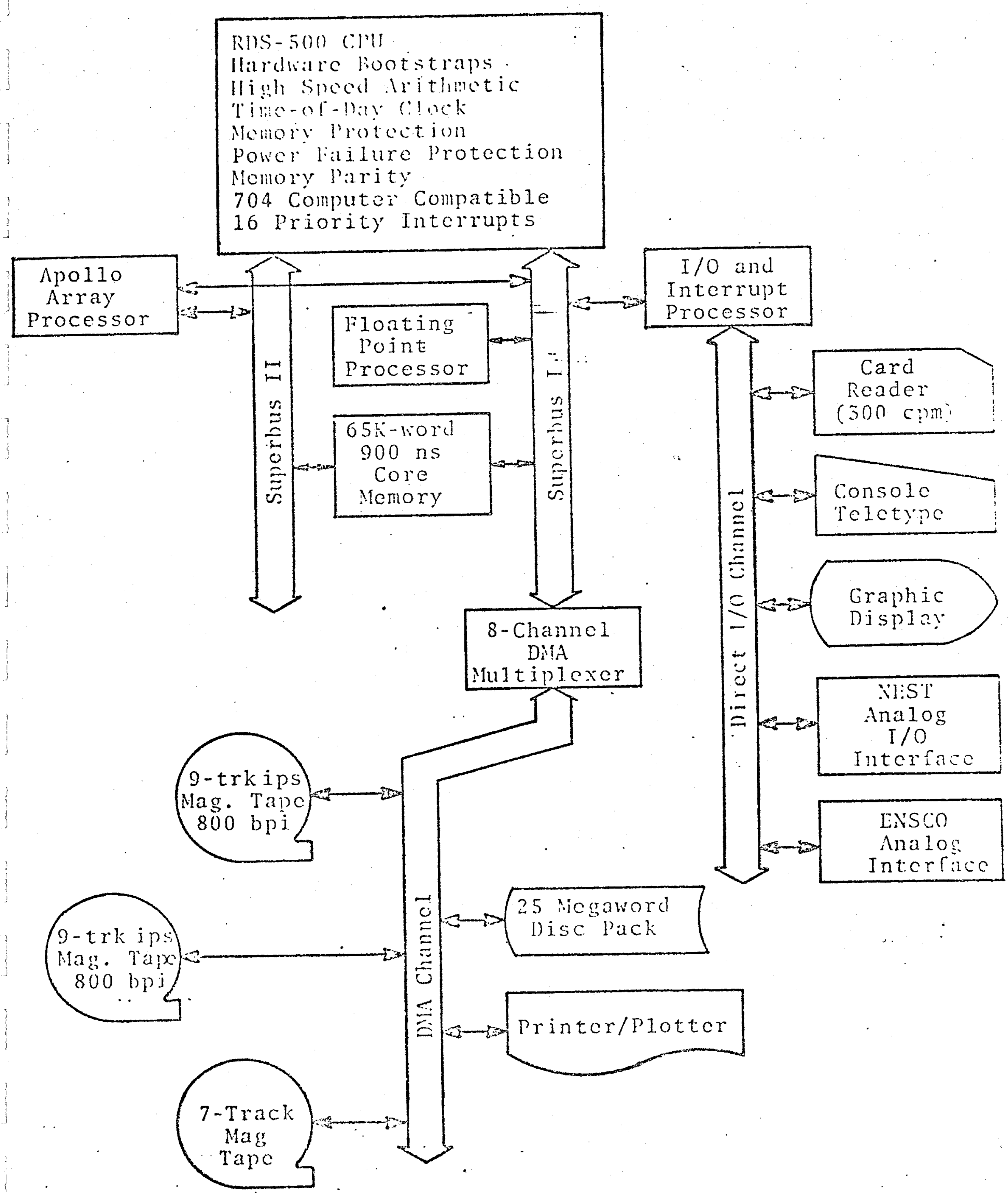


Figure C-1. ENSCO RDS-500 System Configuration

1.2 ISO CRITERIA

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 C-2. Similar curves for the longitudinal direction are shown in Figure C-3.

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. Correspondingly, a factor of 0.315 (or -10 dB) is introduced to obtain the set of curves for the reduced-comfort 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 criteria 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.

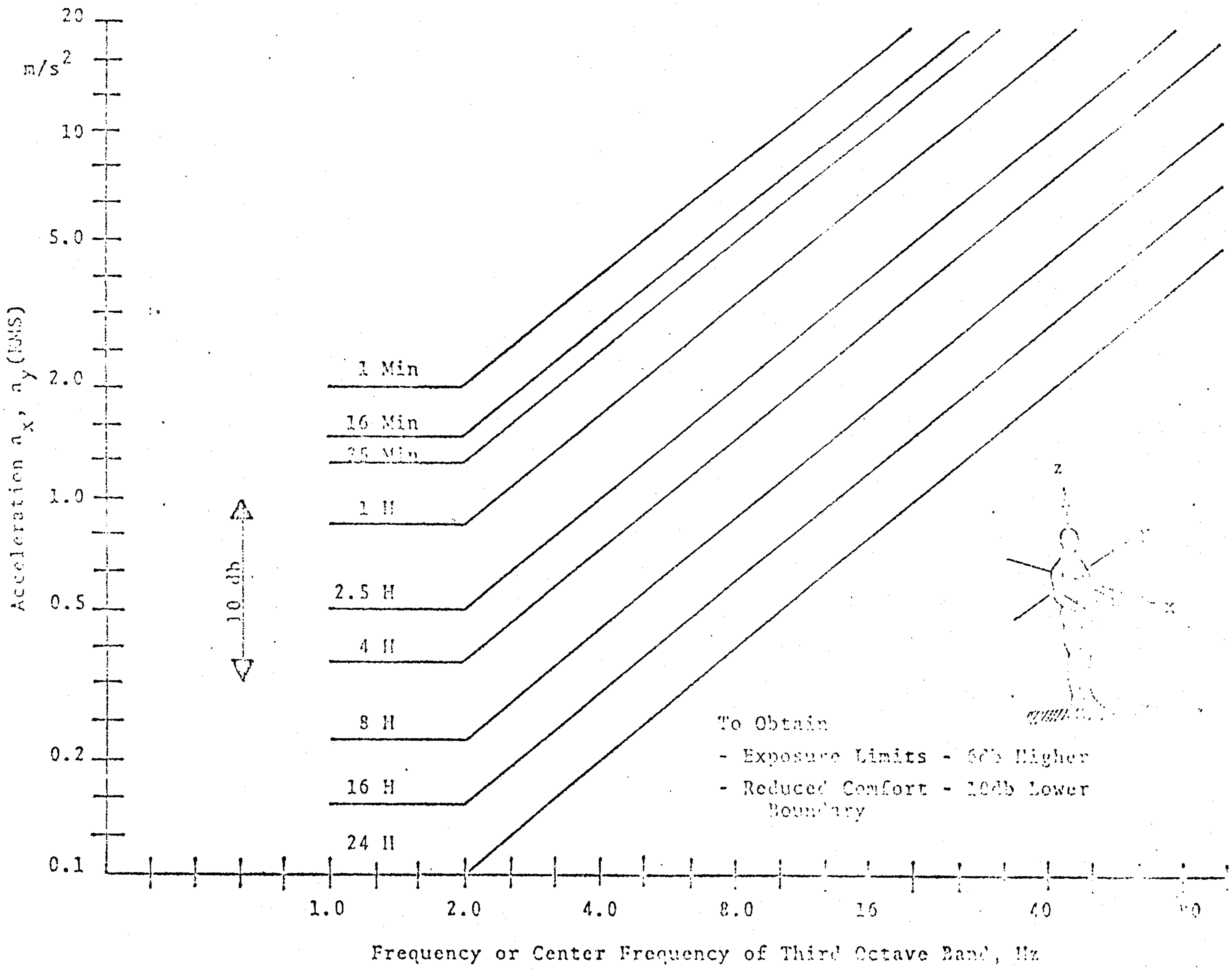


Figure C-2. Transverse Acceleration as a Function of Frequency and Exposure Time (Fatigue-Decreased Proficiency Boundary)

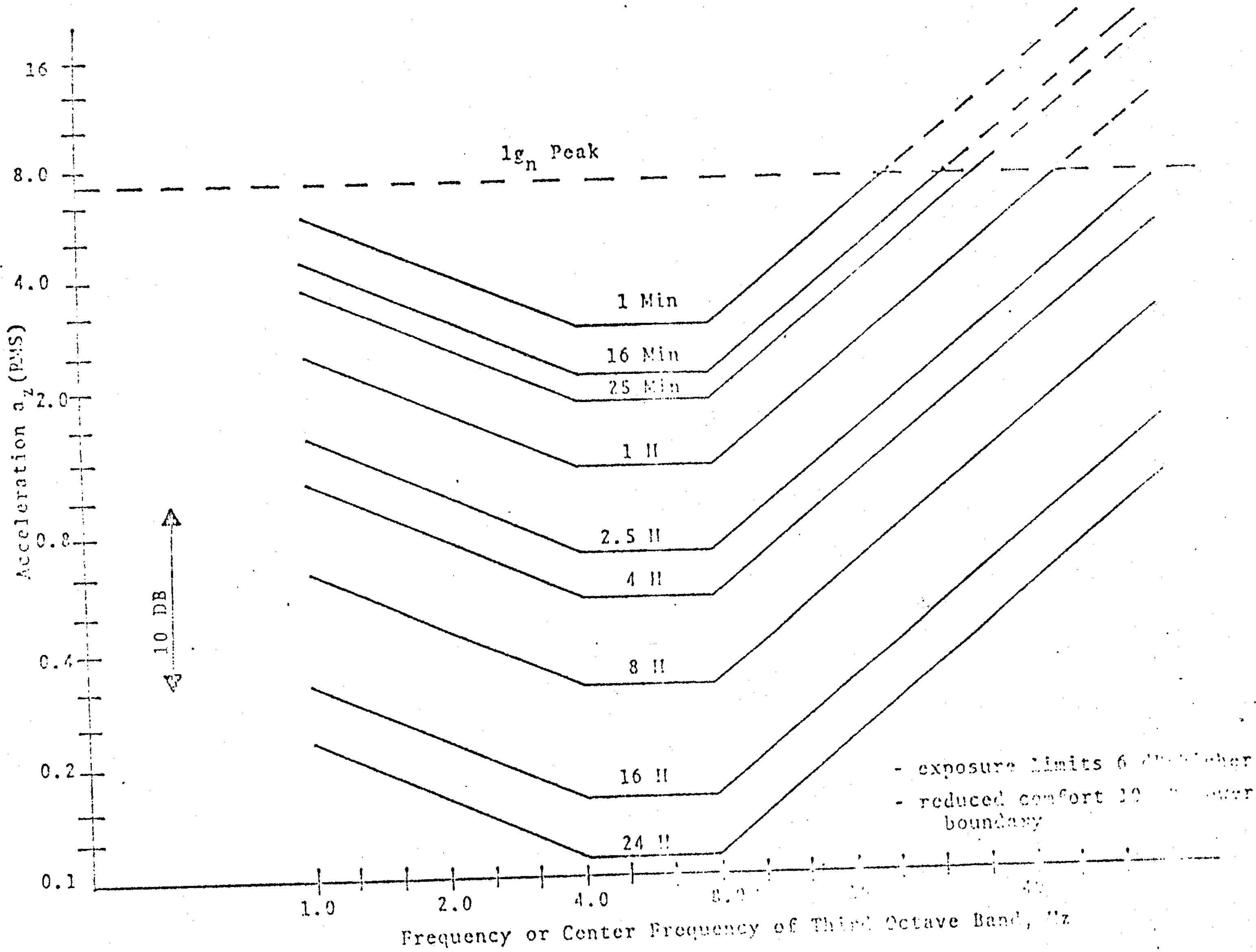


Figure C-3. Longitudinal Acceleration Limits as a Function of Frequency and Exposure Time (Fatigue-Decreased Proficiency Boundary)

1.3 W_z RATING OF RIDE QUALITY

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 one 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.

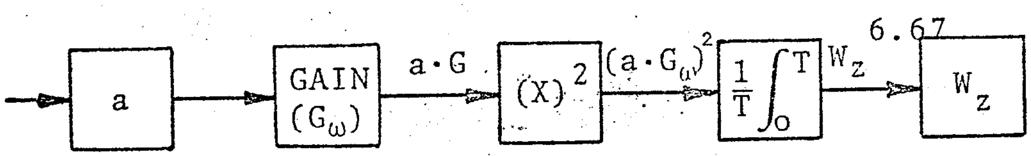
A formula for computing W_z was derived from these experimental results. W_z was defined as a function of both acceleration level and frequency. There are several points to be noted. First, no distinction was seen between vertical and horizontal vibrations in the frequency domain. This conclusion was 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% when the acceleration level doubles in amplitude. Third, on a five point scale, where 1 is an excellent ride and 5 a dangerous one, 3 was selected as the upper limit for passenger cars.

In 1968, Sperling (2) wrote a paper which updates 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 the method is outdated and that poor experimental procedures were used in developing the method. However, he does feel that modifications to the method (weighing factors and integration over the entire frequency range) have improved the method.

The W_z method of rating 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, averaged over time and the 6.67th root is taken. This final number is the W_z rating. Figure C-4 shows a flowchart of the process. The working units are cm/sec^2 for acceleration.

Figure C-4. Flowchart of W_z Method



In general

$$W_z = \sqrt[6.67]{\frac{.896}{T} \int_0^T (G_\omega \cdot A)^2 \, dt}$$

where

W_z = criteria number

T = total time of data sampled

G_ω = 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.

There are slight differences between the W_z and ISO criteria. 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 1-2 Hz for lateral accelerations and at 4-8 Hz for vertical accelerations.

1.4 COMPARISON BETWEEN ISO AND W_z

In making comparison of the W_z Method and the Alternate ISO Standard, one must first investigate the weighting function used with each method. A comparison between the lateral and vertical weighting functions for the ISO criteria is shown in Figure C-5. Figure C-6 shows the same comparison for the W_z rating scheme. It can be seen that there are major differences in the weighting functions. Figures C-7 and C-8 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 1-2 Hz. The greatest sensitivity in the W_z Method is 6-8 Hz.

Next, we can make a comparison between the two methods. Figure C-9 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. These results are shown in Figure C-10.

Finally, we can make a comparison between the ISO and Alternate ISO Standards. A flowchart is seen in Figure C-11. 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 criteria.

FIG. C-5. COMPARISON BETWEEN LATERAL AND VERTICAL ISO WEIGHTING FUNCTION

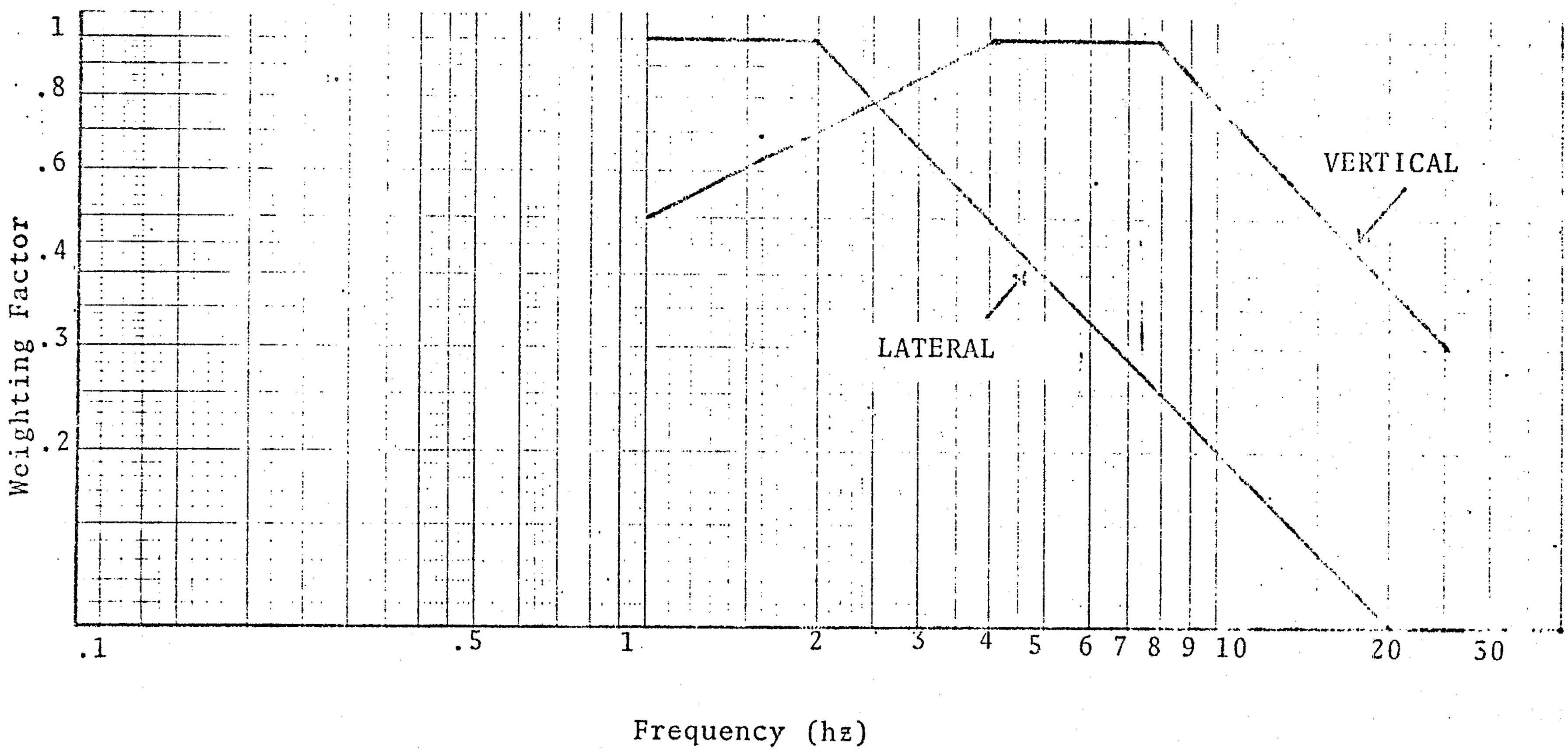


FIG. C-6. COMPARISON BETWEEN LATERAL AND VERTICAL WZ WEIGHTING FUNCTION - VERTICAL

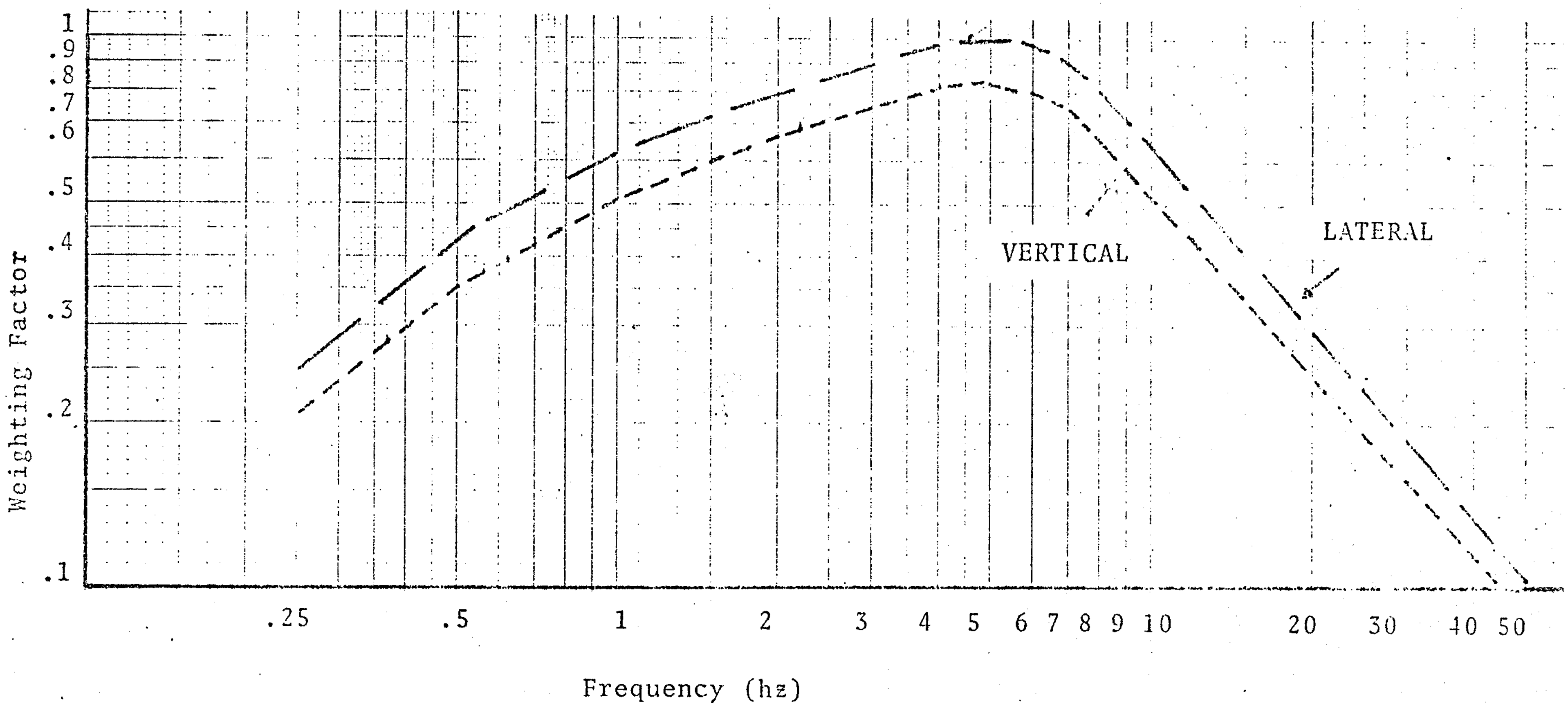


FIG. C-7. COMPARISON BETWEEN ISO AND WZ WEIGHTING FUNCTION - VERTICAL

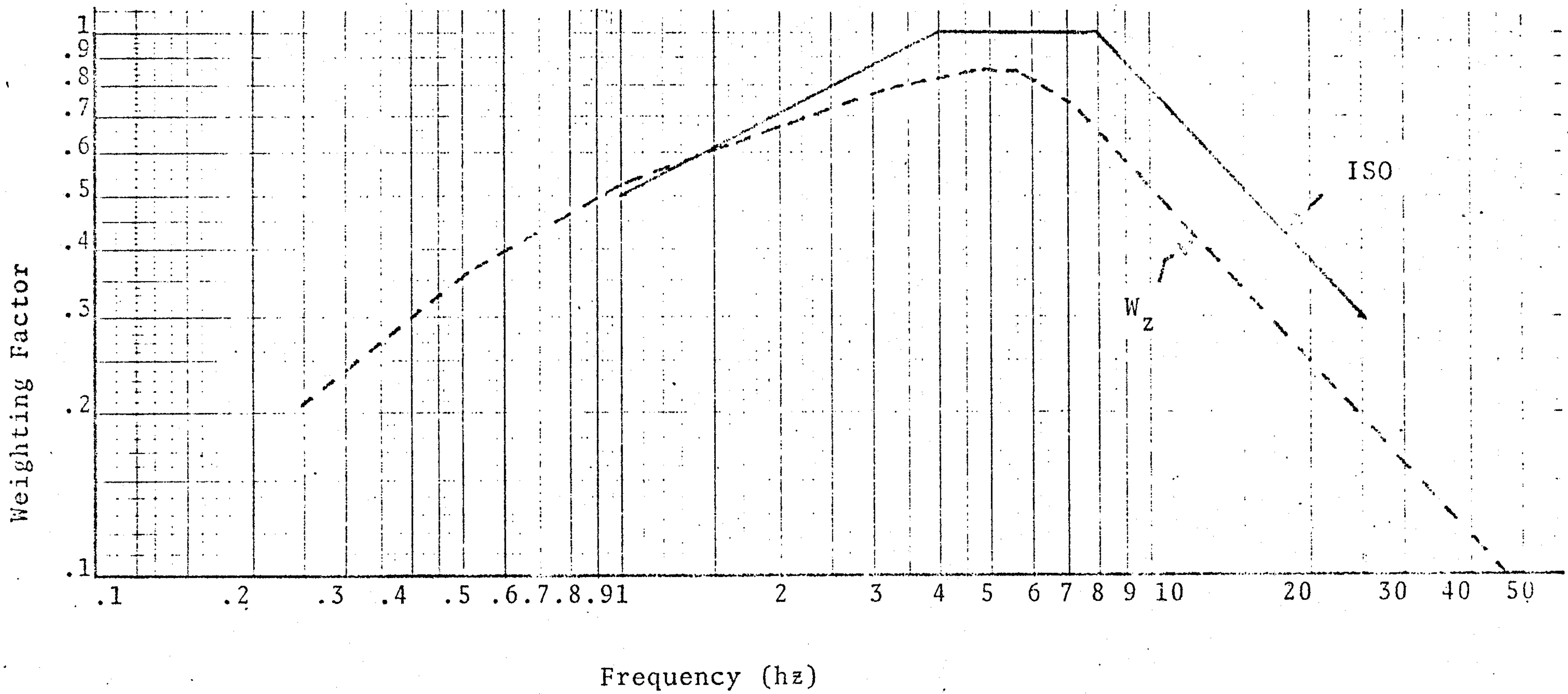
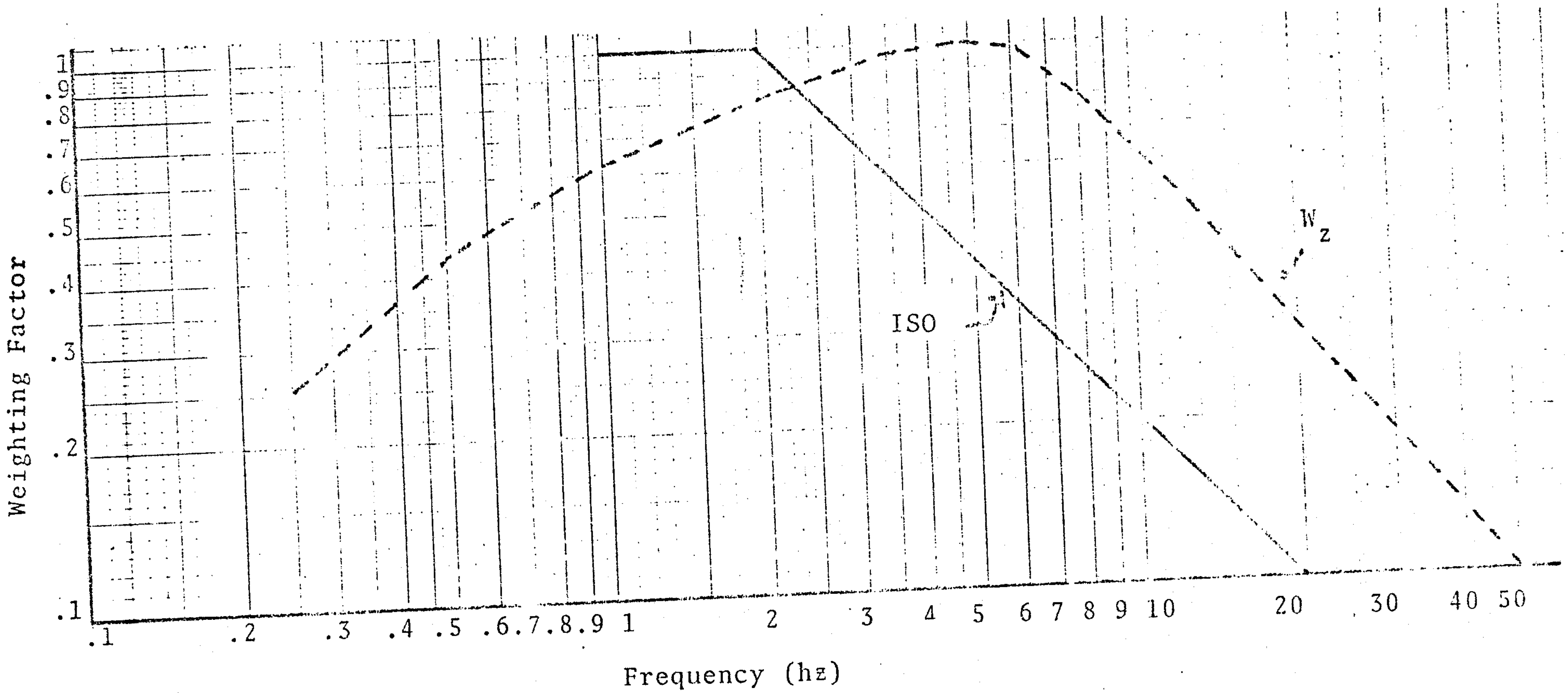


FIG. C-8. COMPARISON BETWEEN ISO AND WZ WEIGHTING FUNCTION - LATERAL



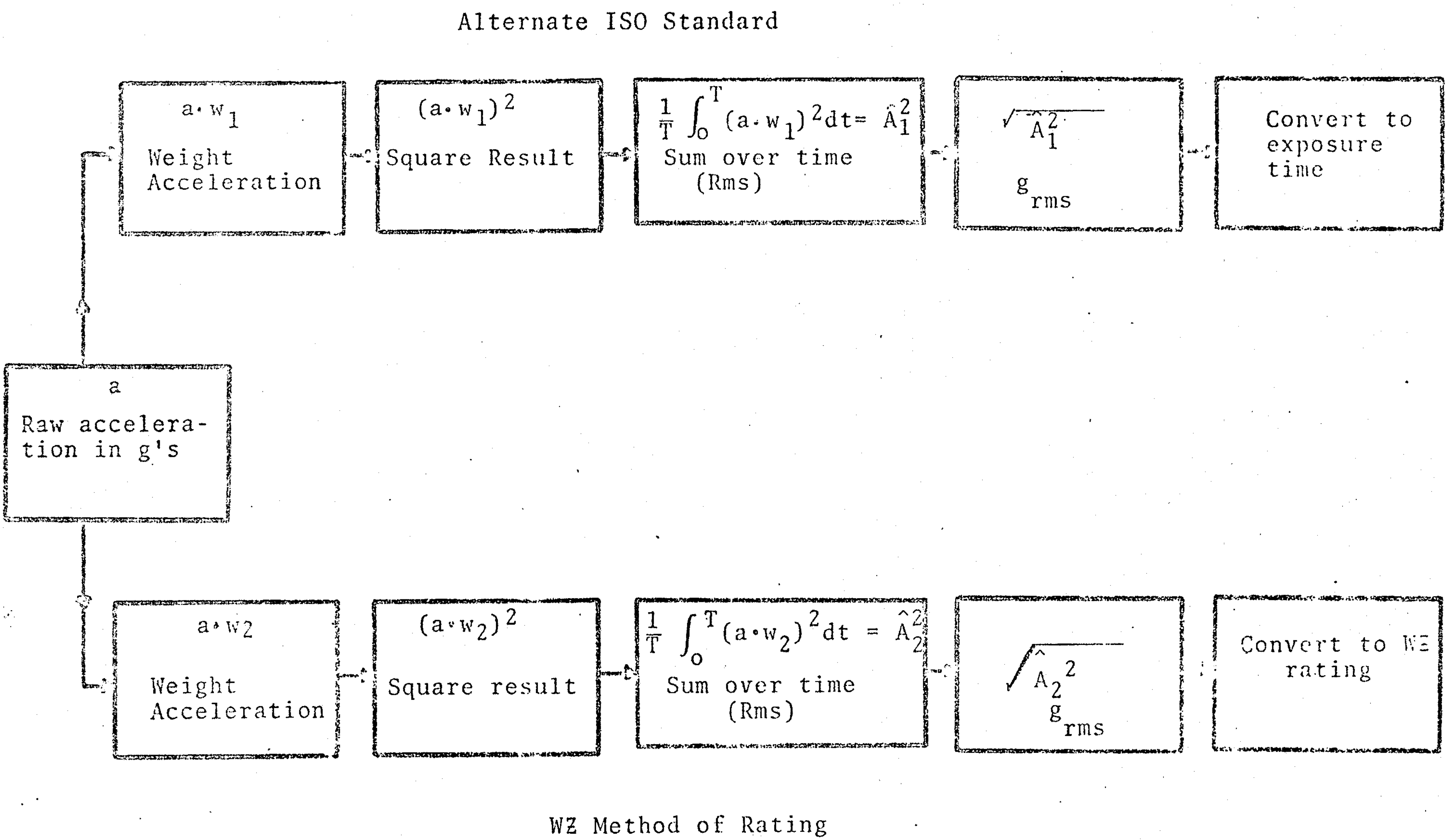


Figure C-9. Comparison Between the WZ and Alternate ISO Standards

ISO EXPOSURE TIME AND W_z RATING

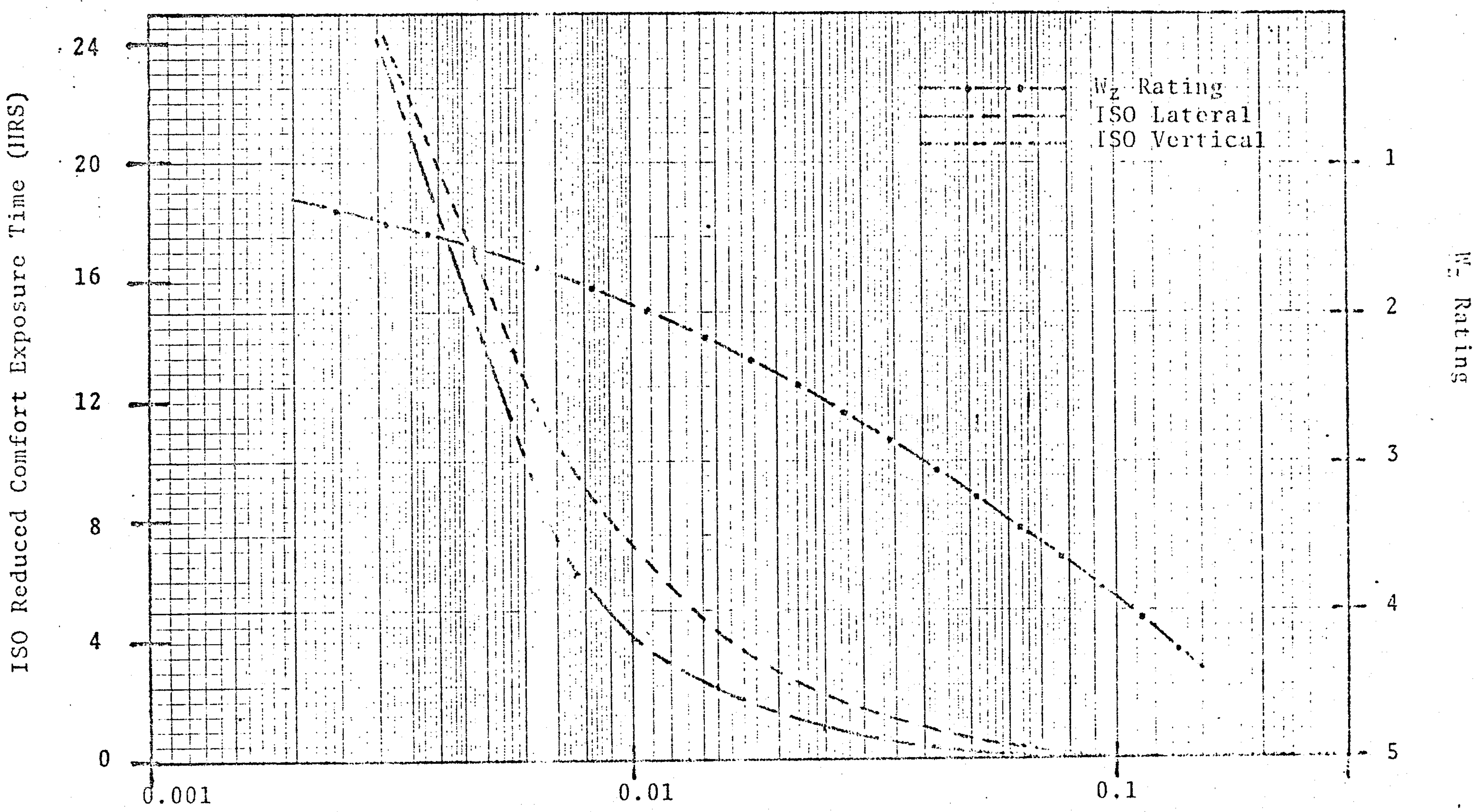


Figure C-10. ACCELERATION LEVEL (g's)

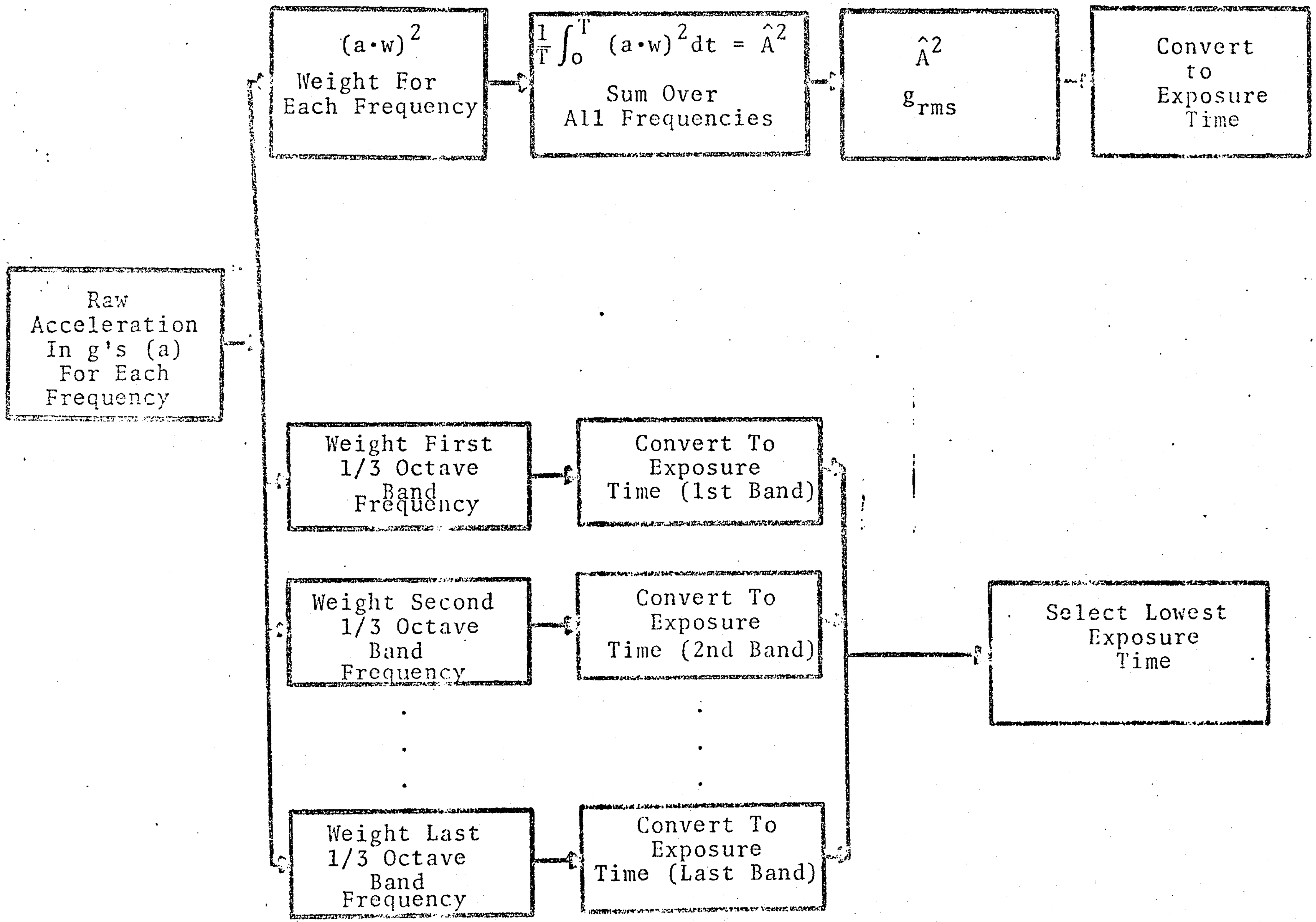


Figure C-11. ISO CRITERIA

REFERENCES

(1) Helberg, W. And Sperling, "Verfahren zur Beurteilung der Laufeigenschaften von Eisenbahnwagen." Organ fur die Fortschutte des Eisenbahwesens, 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, Dr. -ING, 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 Intitutional Development.

(3) Pribnow, Hans-Hermann, "A Simplified Method for Comparitive Evaluation of Ride Quality of Rail Vehicles."

(4) Andrew, Ian, "Ride Index Obsolete," Rail International August 1975, p 319.

APPENDIX D

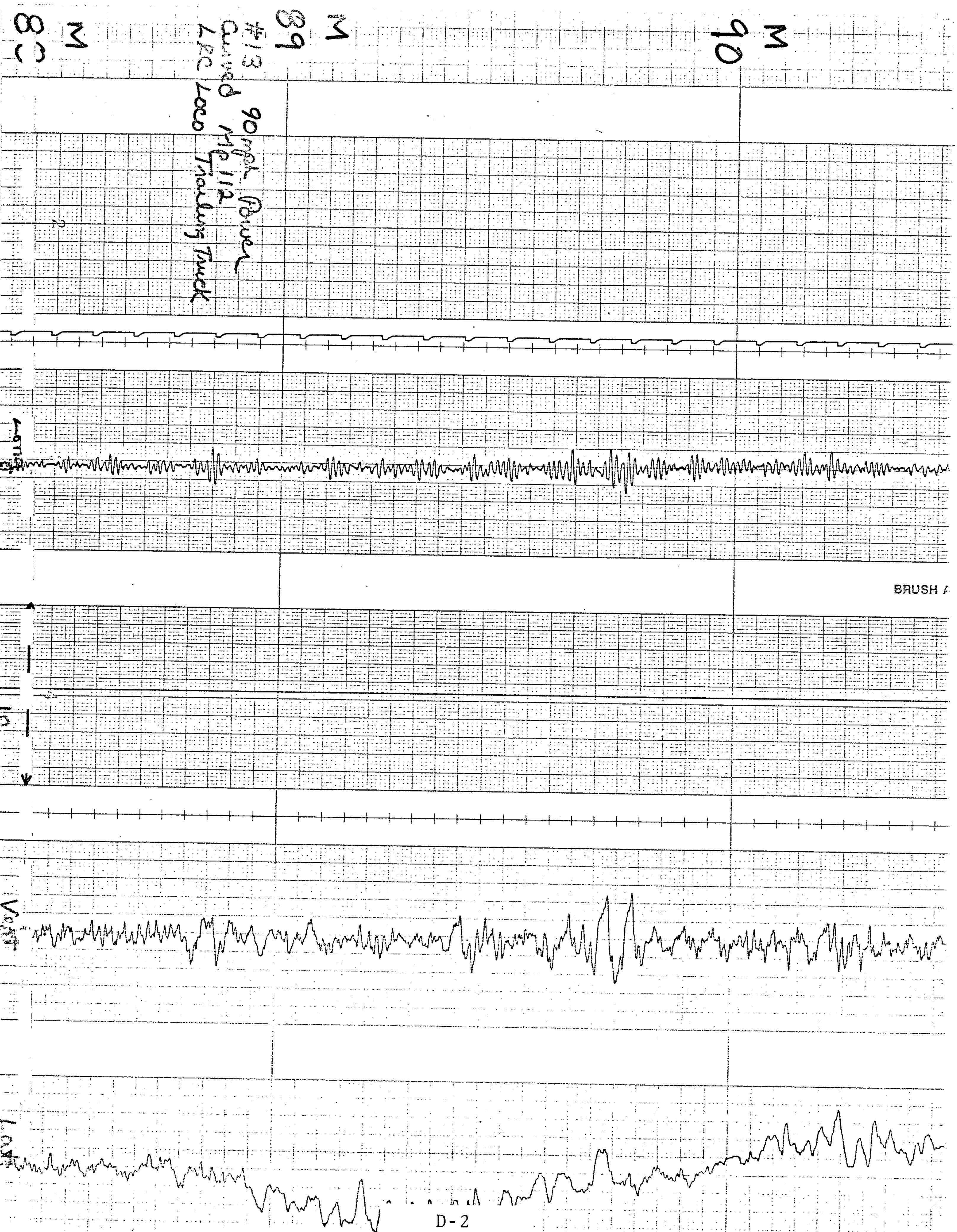
RAW DATA SECTIONS

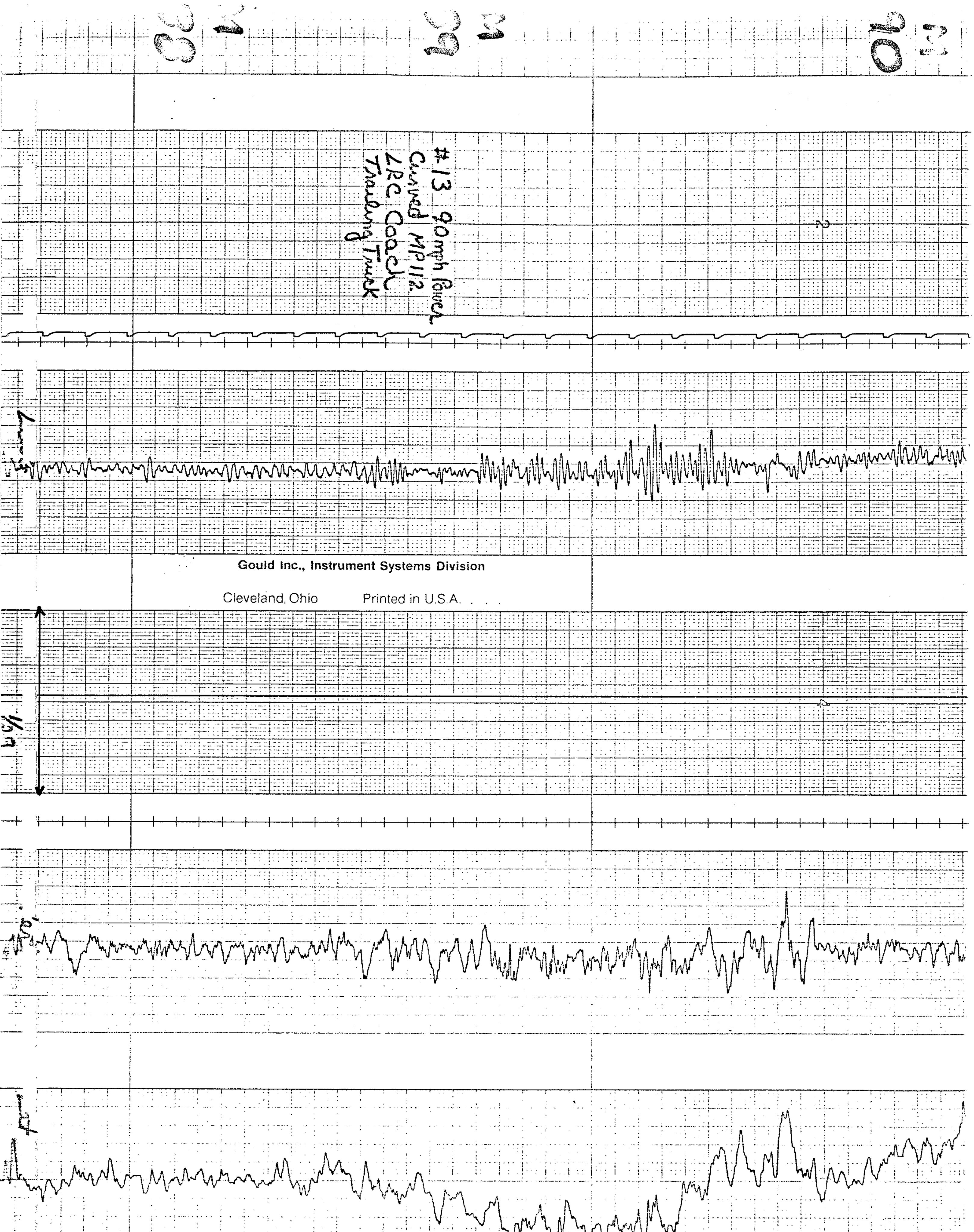
RAW DATA SECTIONS

In the course of analyzing data collected on any test, the first step is to reproduce the signals on a strip chart recorder. This enables the analyst to validate the following:

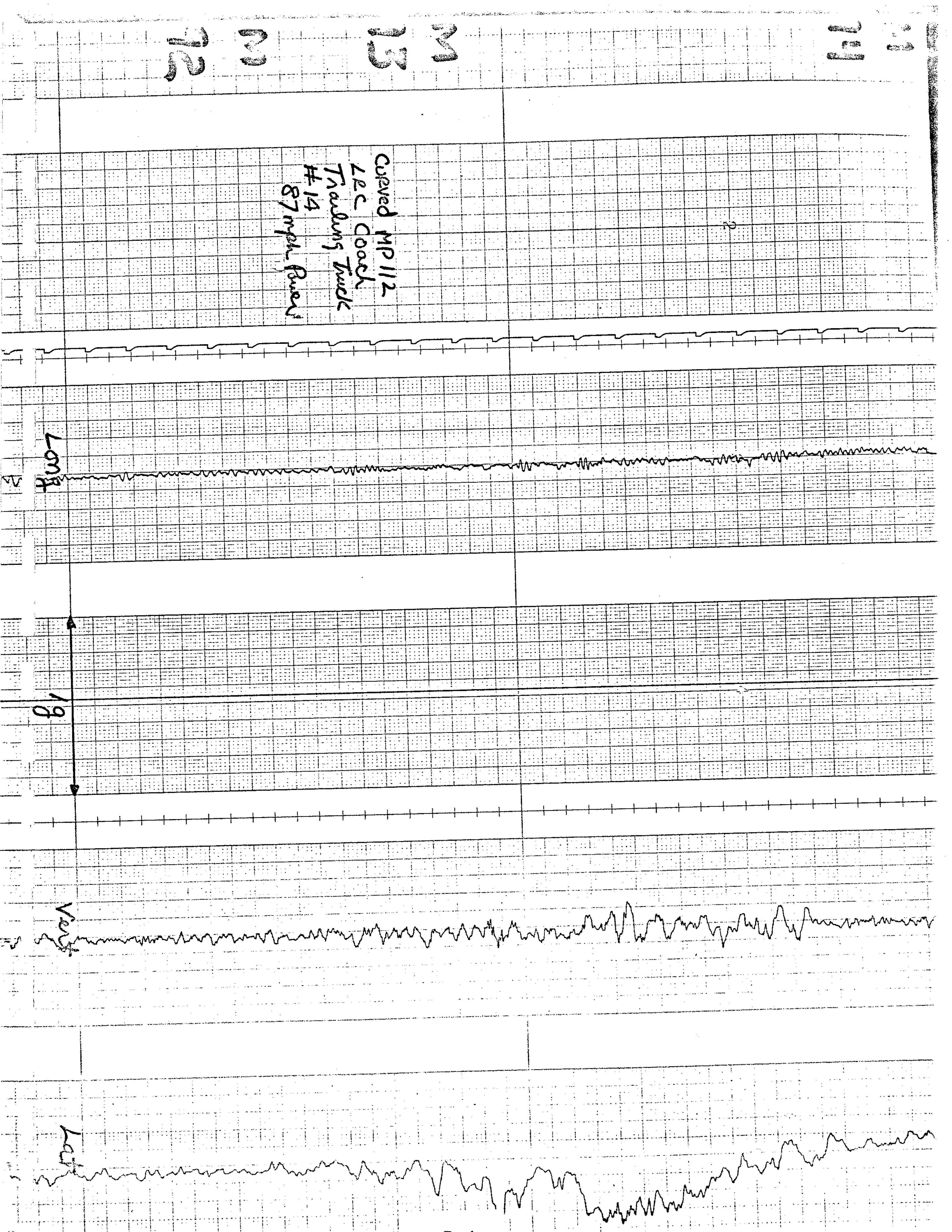
1) To insure that data was physically recorded on tape
2) To conduct a preliminary analysis and obtain a better understanding of the dynamic movements of the vehicle

Stripped out segments of the high speed runs are included in this Appendix. Signals from the lateral, vertical, and longitudinal accelerometers are indicated. One second time increments and message units are also shown.

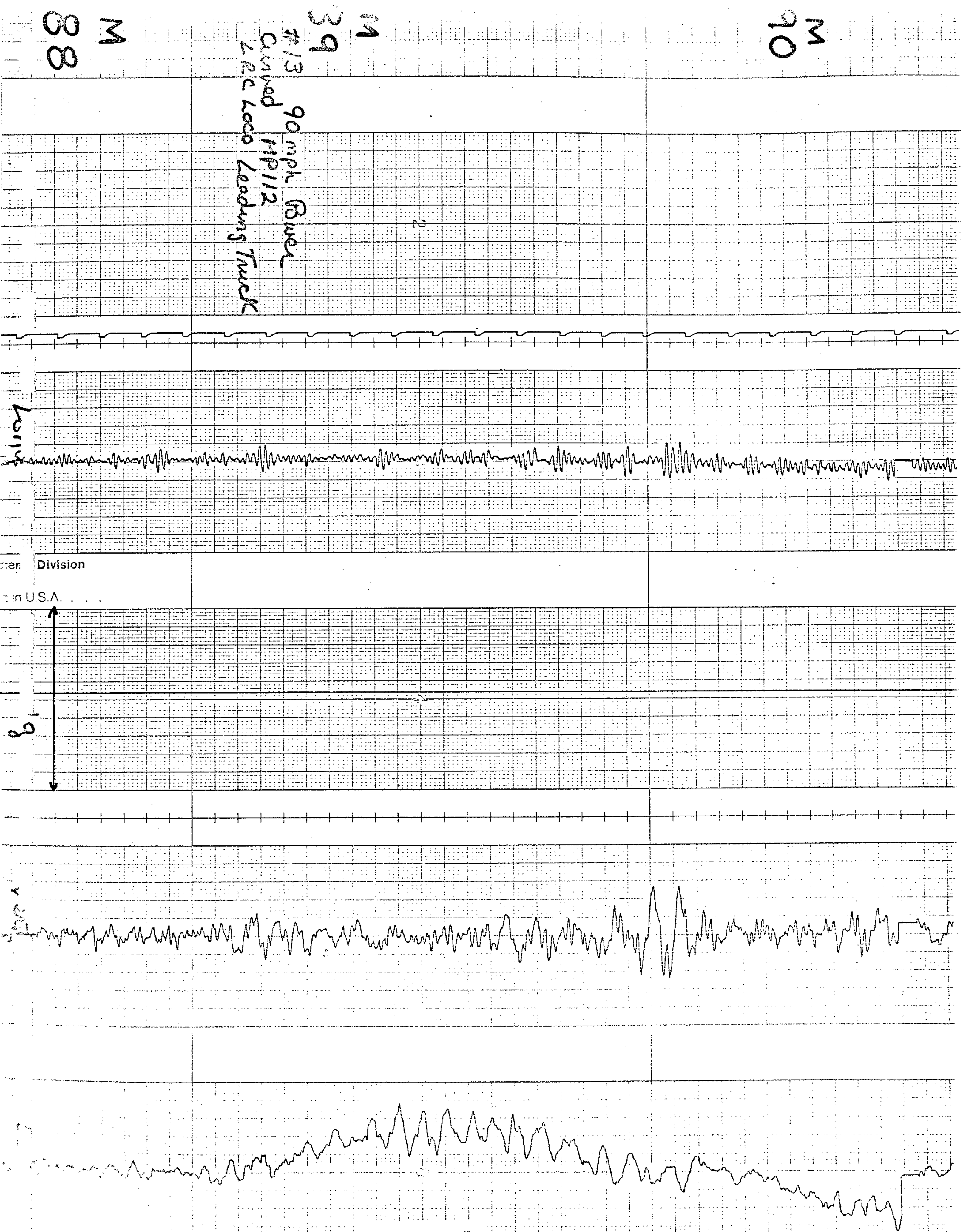

M 89
M 90
#13 90mph Power
Curved MC 112
LRC Loco Trailing Truck
BRUSH

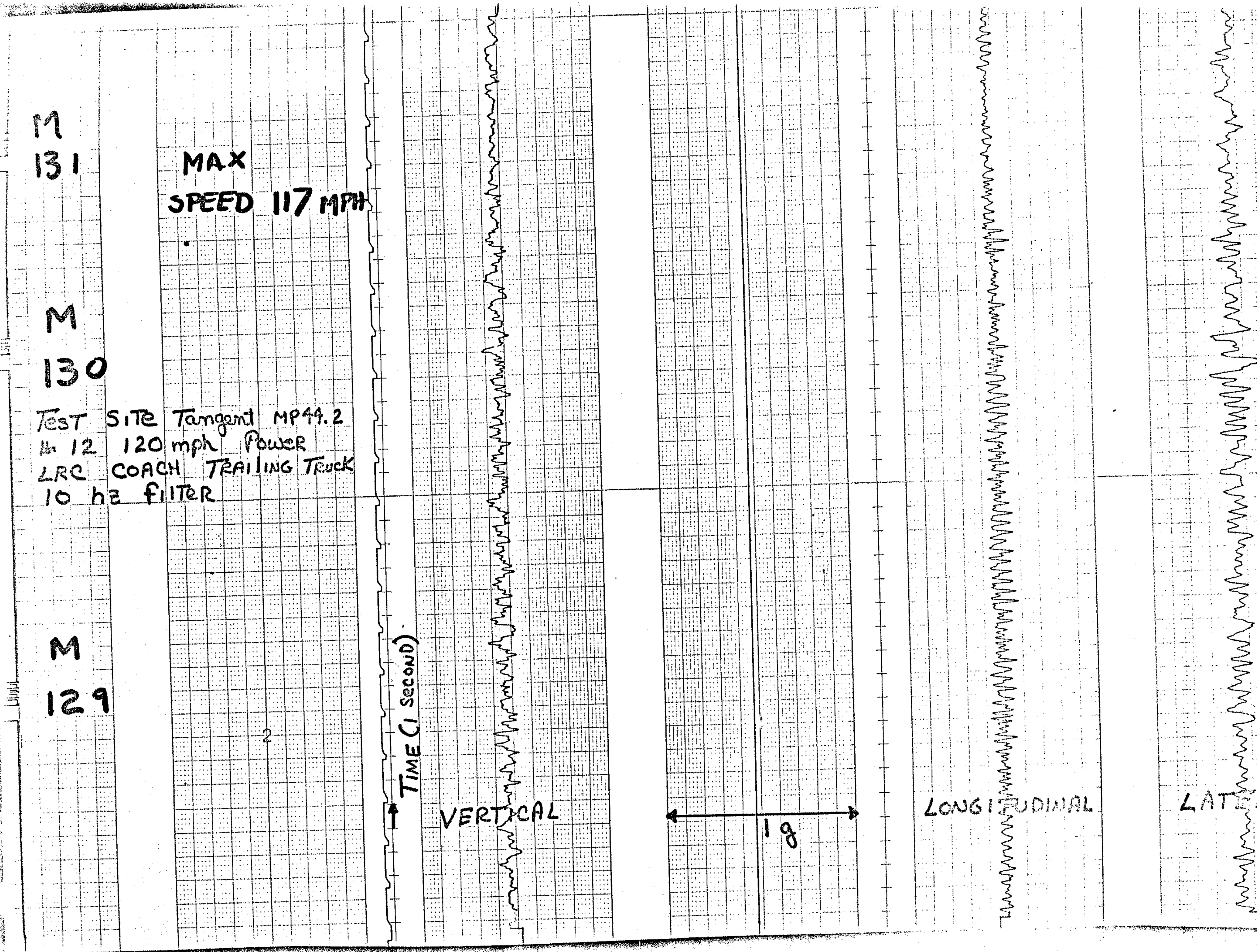


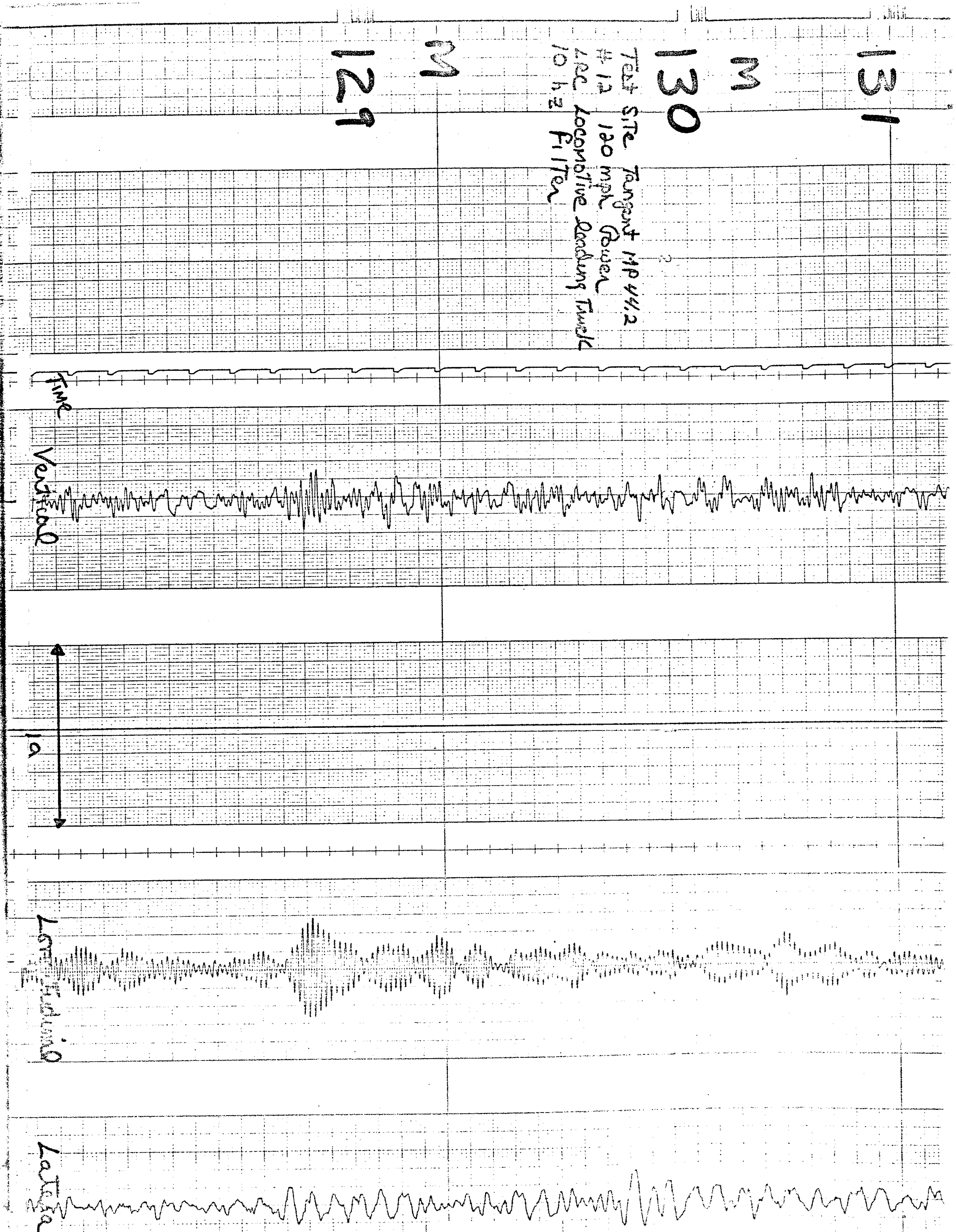
88
89
90
#13 90mph Power
Curved MP112
LRC Coach
Trailing Truck
Gould Inc., Instrument Systems Division
Cleveland, Ohio
Printed in U.S.A.

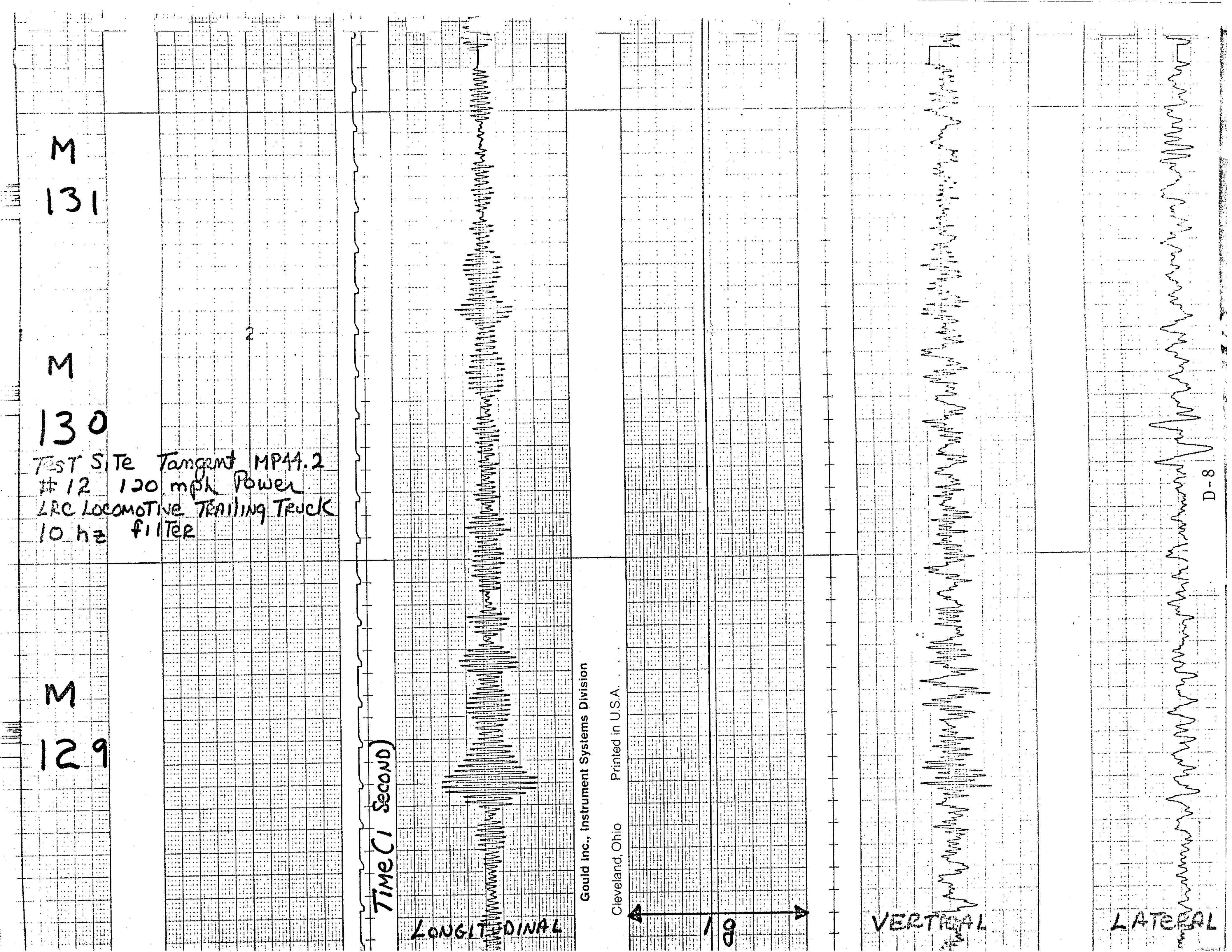


Curved MP 112
LEC Coach
Trailing Truck
#14
87 mph Power
Long
1g
Vert
Lat


M 88
M 89
#13 90 mph Power
Curved HP112
Leading Truck
M 90
Division
in U.S.A.


M
131
MAX
SPEED 117 MPH
M
130
Test Site Tangent MP44.2
12 120 mph Power
LRC COACH TRAILING TRUCK
10 hz filter
M
129
2
TIME (1 SECOND)
VERTICAL
1 g
LONGITUDINAL
LATERA


131
M
130
Test Site Tangent MP 44.2
#12 120 mph Power
Lee Locomotive Leading Truck
10 hz Filter
M
129
Time
Vertical
1g
Longitudinal
Lateral


M
131
M
130
TEST SITE Tangent MP44.2
#12 120 mph Power
LRC Locomotive Trailing Truck
10 hz filter
M
129
2
TIME (1 SECOND)
LONGITUDINAL
Gould Inc., Instrument Systems Division
Cleveland, Ohio Printed in U.S.A.
1g
VERTICAL
LATERAL

APPENDIX E

SAMPLE SOFTWARE OUTPUT

VEHICLE VIBRATION DATA REDUCTION PACKAGE (VIBES)

The input to this program consists of six channels of data per run. This data is set up in records containing 128 scans (1 second). 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 comfort criteria
- Power spectral density levels and plots
- Cepstrum plots for PSD levels
- RMS levels

The format of the otuput 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. This page has twelve columns, two 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 can include both the channel number and a short description of what data was 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 and location of test, number of scans and record numbers).

The units are g's for linear acceleration channels and radians/second/second for rotational acceleration channels. At the end of page 2, the standard deviation of the six channels is given. The standard deviations of the data are given in engineering units (such as g's and radians/second/second) based on the scale factor for each channel. The scale factor relates the voltage level to the measured engineering units (g/volt). The data is digitized at a rate of 128 Hz and one second of data is recorded per record. Thus, the number of scans (data points) corresponds to the number of records times 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 column one corresponding to a voltage setting and column two 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 va-ue - EV) along with the mean plus or minus one standard deviation (UB - upper band, LB - lower band).

The one-third octave band filtered results for ride comfort are shown on page 7. For center frequencies ranging from 1.0 to 31.5 Hz, time limits for reduced comfort are given for longitudinal, lateral, and vertical accelerations. In addition, a summary section reports the minimum exposure limits along with the frequencies at which it occurs.

Pages 8 through 10 give the power spectral density level (PSD) in dB which corresponds to a given frequency. These levels are printed for each channel and for frequencies from 0.25 to 40.0 Hz.

Page 11 is a short summary of the results. First, a description of the test run is given. Then, for the linear acceleration channels, the following information is given:

- standard deviation
- 99 percentile level
- 95 percentile level
- reduced comfort exposure time
- center frequency
- alternate exposure time (frequency weighted)
- W_z method (frequency weighted) where 1 is a good ride and 5 is a bad ride

Cepstrum plots of power spectral density in one-third octave bands are given on page 12. These plots indicate the amount of change in each one-third octave band over a period of time.

Plots of the probability density estimate and the distribution function estimate are given on pages 13 and 14. These graphs are plotted as a function of acceleration level.

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 (SPD) level in dB relative to 1g (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, 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.

A flow chart of the processing is shown in Figure 12.

A sample copy of the output is given in Appendix B.

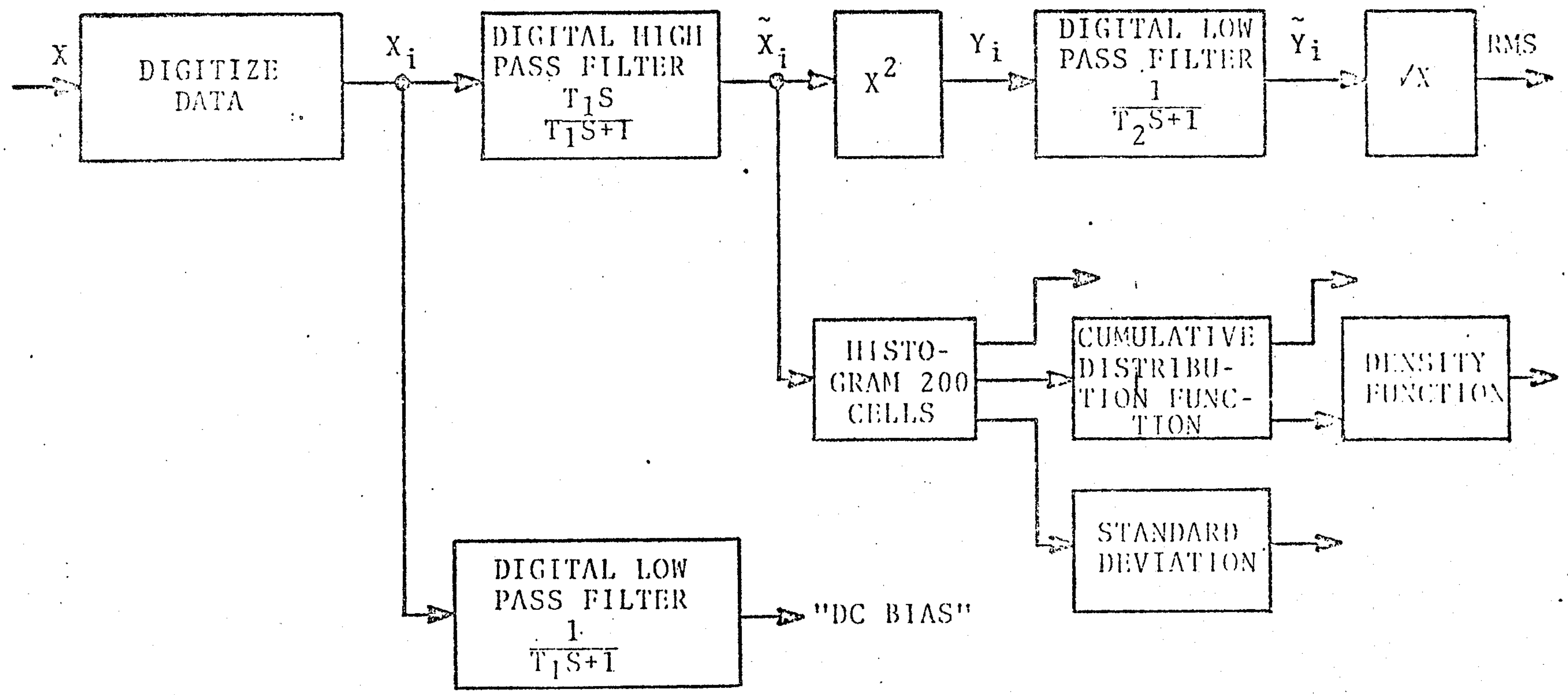


Figure 12. Block Diagram for Data Reduction (One Channel)

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

FILE18 LRC TEST CURVED LOCOMOTIVE RUN 17 67 MPH DRIFT

RUN 17

3072. SCANS

G'S	VERT1	G'S	LONG1	G'S	LAT1	G'S	VERT2	G'S	LONG2	G'S	LAT2
-0.96	0.00000	-0.96	0.00000	-0.96	0.00000	-0.96	0.00000	-0.96	0.00000	-0.96	0.00000
-0.92	0.00000	-0.92	0.00000	-0.92	0.00000	-0.92	0.00000	-0.92	0.00000	-0.92	0.00000
-0.88	0.00000	-0.88	0.00000	-0.88	0.00000	-0.88	0.00000	-0.88	0.00000	-0.88	0.00000
-0.84	0.00000	-0.84	0.00000	-0.84	0.00000	-0.84	0.00000	-0.84	0.00000	-0.84	0.00000
-0.80	0.00000	-0.80	0.00000	-0.80	0.00000	-0.80	0.00000	-0.80	0.00000	-0.80	0.00000
-0.76	0.00000	-0.76	0.00000	-0.76	0.00000	-0.76	0.00000	-0.76	0.00000	-0.76	0.00000
-0.72	0.00000	-0.72	0.00000	-0.72	0.00000	-0.72	0.00000	-0.72	0.00000	-0.72	0.00000
-0.68	0.00000	-0.68	0.00000	-0.68	0.00000	-0.68	0.00000	-0.68	0.00000	-0.68	0.00000
-0.64	0.00000	-0.64	0.00000	-0.64	0.00000	-0.64	0.00000	-0.64	0.00000	-0.64	0.00000
-0.60	0.00000	-0.60	0.00000	-0.60	0.00000	-0.60	0.00000	-0.60	0.00000	-0.60	0.00000
-0.58	0.00000	-0.58	0.00000	-0.58	0.00000	-0.58	0.00000	-0.58	0.00000	-0.58	0.00000
-0.56	0.00000	-0.56	0.00000	-0.56	0.00000	-0.56	0.00000	-0.56	0.00000	-0.56	0.00000
-0.54	0.00000	-0.54	0.00000	-0.54	0.00000	-0.54	0.00000	-0.54	0.00000	-0.54	0.00000
-0.52	0.00000	-0.52	0.00000	-0.52	0.00000	-0.52	0.00000	-0.52	0.00000	-0.52	0.00000
-0.50	0.00000	-0.50	0.00000	-0.50	0.00000	-0.50	0.00000	-0.50	0.00000	-0.50	0.00000
-0.48	0.00000	-0.48	0.00000	-0.48	0.00000	-0.48	0.00000	-0.48	0.00000	-0.48	0.00000
-0.46	0.00000	-0.46	0.00000	-0.46	0.00000	-0.46	0.00000	-0.46	0.00000	-0.46	0.00000
-0.44	0.00000	-0.44	0.00000	-0.44	0.00000	-0.44	0.00000	-0.44	0.00000	-0.44	0.00000
-0.42	0.00000	-0.42	0.00000	-0.42	0.00000	-0.42	0.00000	-0.42	0.00000	-0.42	0.00000
-0.40	0.00000	-0.40	0.00000	-0.40	0.00000	-0.40	0.00000	-0.40	0.00000	-0.40	0.00000
-0.39	0.00000	-0.39	0.00000	-0.39	0.00000	-0.39	0.00000	-0.39	0.00000	-0.39	0.00000
-0.38	0.00000	-0.38	0.00000	-0.38	0.00000	-0.38	0.00000	-0.38	0.00000	-0.38	0.00000
-0.37	0.00000	-0.37	0.00000	-0.37	0.00000	-0.37	0.00000	-0.37	0.00000	-0.37	0.00000
-0.36	0.00000	-0.36	0.00000	-0.36	0.00000	-0.36	0.00000	-0.36	0.00000	-0.36	0.00000
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-0.34	0.00000	-0.34	0.00000	-0.34	0.00000	-0.34	0.00000	-0.34	0.00000	-0.34	0.00000
-0.33	0.00000	-0.33	0.00000	-0.33	0.00000	-0.33	0.00000	-0.33	0.00000	-0.33	0.00000
-0.32	0.00000	-0.32	0.00000	-0.32	0.00000	-0.32	0.00000	-0.32	0.00000	-0.32	0.00000
-0.31	0.00000	-0.31	0.00000	-0.31	0.00000	-0.31	0.00000	-0.31	0.00000	-0.31	0.00000
-0.30	0.00000	-0.30	0.00000	-0.30	0.00000	-0.30	0.00000	-0.30	0.00000	-0.30	0.00000
-0.29	0.00000	-0.29	0.00000	-0.29	0.00000	-0.29	0.00000	-0.29	0.00000	-0.29	0.00000
-0.28	0.00000	-0.28	0.00000	-0.28	0.00000	-0.28	0.00000	-0.28	0.00000	-0.28	0.00000
-0.27	0.00000	-0.27	0.00000	-0.27	0.00000	-0.27	0.00000	-0.27	0.00000	-0.27	0.00000
-0.26	0.00000	-0.26	0.00000	-0.26	0.00000	-0.26	0.00000	-0.26	0.00000	-0.26	0.00000
-0.25	0.03255	-0.25	0.00000	-0.25	0.00000	-0.25	0.00000	-0.25	0.00000	-0.25	0.00000
-0.24	0.03255	-0.24	0.00000	-0.24	0.00000	-0.24	0.00000	-0.24	0.00000	-0.24	0.00000
-0.23	0.06510	-0.23	0.00000	-0.23	0.00000	-0.23	0.00000	-0.23	0.00000	-0.23	0.00000
-0.22	0.03255	-0.22	0.00000	-0.22	0.00000	-0.22	0.00000	-0.22	0.00000	-0.22	0.00000
-0.21	0.03255	-0.21	0.00000	-0.21	0.00000	-0.21	0.00000	-0.21	0.00000	-0.21	0.00000
-0.20	0.09766	-0.20	0.00000	-0.20	0.00000	-0.20	0.00000	-0.20	0.00000	-0.20	0.00000
-0.19	0.03255	-0.19	0.00000	-0.19	0.00000	-0.19	0.00000	-0.19	0.00000	-0.19	0.00000
-0.18	0.06510	-0.18	0.00000	-0.18	0.00000	-0.18	0.00000	-0.18	0.00000	-0.18	0.00000
-0.17	0.00000	-0.17	0.00000	-0.17	0.00000	-0.17	0.03255	-0.17	0.00000	-0.17	0.00000
-0.16	0.00000	-0.16	0.00000	-0.16	0.00000	-0.16	0.09766	-0.16	0.00000	-0.16	0.00000
-0.15	0.06510	-0.15	0.00000	-0.15	0.00000	-0.15	0.06510	-0.15	0.00000	-0.15	0.00000
-0.14	0.16276	-0.14	0.00000	-0.14	0.00000	-0.14	0.03255	-0.14	0.00000	-0.14	0.00000
-0.13	0.22786	-0.13	0.00000	-0.13	0.00000	-0.13	0.19531	-0.13	0.00000	-0.13	0.00000
-0.12	0.35807	-0.12	0.00000	-0.12	0.00000	-0.12	0.13021	-0.12	0.00000	-0.12	0.00000
-0.11	0.45573	-0.11	0.00000	-0.11	0.00000	-0.11	0.19531	-0.11	0.00000	-0.11	0.00000
-0.10	0.68359	-0.10	0.00000	-0.10	0.00000	-0.10	0.39063	-0.10	0.00000	-0.10	0.03255
-0.09	1.52995	-0.09	0.00000	-0.09	0.00000	-0.09	0.65104	-0.09	0.03255	-0.09	0.29297
-0.08	1.66016	-0.08	0.00000	-0.08	0.68359	-0.08	0.97656	-0.08	0.09766	-0.08	0.55339
-0.07	2.70182	-0.07	0.22786	-0.07	1.07422	-0.07	2.14844	-0.07	0.26042	-0.07	1.26953
-0.06	2.70182	-0.06	0.55339	-0.06	1.46484	-0.06	2.63672	-0.06	0.74870	-0.06	2.31120
-0.05	3.51563	-0.05	1.62760	-0.05	3.19010	-0.05	3.77604	-0.05	1.62760	-0.05	1.98568
-0.04	5.07813	-0.04	3.05990	-0.04	3.87370	-0.04	5.63151	-0.04	3.25521	-0.04	4.98047
-0.03	6.18490	-0.03	5.85938	-0.03	5.89193	-0.03	6.18490	-0.03	6.08724	-0.03	6.83594
-0.02	6.96615	-0.02	11.84896	-0.02	8.98438	-0.02	8.36589	-0.02	8.36589	-0.02	9.30990
-0.01	7.32422	-0.01	14.19271	-0.01	12.56511	-0.01	9.63542	-0.01	12.10938	-0.01	10.31901

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	8.56120	-0.00	14.84375	-0.00	12.40234	-0.00	9.83073	-0.00	15.46224	-0.00	12.33724
0.01	8.46354	0.01	15.10417	0.01	13.96485	0.01	9.01693	0.01	15.72266	0.01	12.56511
0.02	9.24479	0.02	12.76042	0.02	12.27214	0.02	9.60287	0.02	14.16016	0.02	11.42578
0.03	6.80339	0.03	8.85417	0.03	7.29167	0.03	7.22656	0.03	10.57943	0.03	8.85417
0.04	6.80339	0.04	5.85938	0.04	6.11979	0.04	7.03125	0.04	6.18490	0.04	6.34766
0.05	6.05469	0.05	2.86458	0.05	4.16667	0.05	4.45964	0.05	3.41797	0.05	4.13412
0.06	3.84115	0.06	1.10677	0.06	3.15755	0.06	3.97135	0.06	1.10677	0.06	2.57161
0.07	3.19010	0.07	0.87891	0.07	1.56250	0.07	2.60417	0.07	0.58594	0.07	1.56250
0.08	2.44141	0.08	0.26042	0.08	0.97656	0.08	1.95313	0.08	0.13021	0.08	0.78125
0.09	1.46484	0.09	0.09766	0.09	0.29297	0.09	1.04167	0.09	0.06510	0.09	0.61849
0.10	1.20443	0.10	0.00000	0.10	0.06510	0.10	0.65104	0.10	0.00000	0.10	0.29297
0.11	0.68359	0.11	0.00000	0.11	0.00000	0.11	0.74870	0.11	0.00000	0.11	0.19531
0.12	0.29297	0.12	0.00000	0.12	0.00000	0.12	0.29297	0.12	0.00000	0.12	0.26042
0.13	0.29297	0.13	0.00000	0.13	0.00000	0.13	0.13021	0.13	0.00000	0.13	0.13021
0.14	0.09766	0.14	0.00000	0.14	0.00000	0.14	0.13021	0.14	0.00000	0.14	0.03255
0.15	0.09766	0.15	0.00000	0.15	0.00000	0.15	0.13021	0.15	0.00000	0.15	0.00000
0.16	0.09766	0.16	0.00000	0.16	0.00000	0.16	0.03255	0.16	0.00000	0.16	0.00000
0.17	0.06510	0.17	0.00000	0.17	0.00000	0.17	0.00000	0.17	0.00000	0.17	0.00000
0.18	0.03255	0.18	0.00000	0.18	0.00000	0.18	0.00000	0.18	0.00000	0.18	0.00000
0.19	0.19531	0.19	0.00000	0.19	0.00000	0.19	0.00000	0.19	0.00000	0.19	0.00000
0.20	0.00000	0.20	0.00000	0.20	0.00000	0.20	0.00000	0.20	0.00000	0.20	0.00000
0.21	0.06510	0.21	0.00000	0.21	0.00000	0.21	0.00000	0.21	0.00000	0.21	0.00000
0.22	0.00000	0.22	0.00000	0.22	0.00000	0.22	0.00000	0.22	0.00000	0.22	0.00000
0.23	0.00000	0.23	0.00000	0.23	0.00000	0.23	0.00000	0.23	0.00000	0.23	0.00000
0.24	0.00000	0.24	0.00000	0.24	0.00000	0.24	0.00000	0.24	0.00000	0.24	0.00000
0.25	0.00000	0.25	0.00000	0.25	0.00000	0.25	0.00000	0.25	0.00000	0.25	0.00000
0.26	0.00000	0.26	0.00000	0.26	0.00000	0.26	0.00000	0.26	0.00000	0.26	0.00000
0.27	0.00000	0.27	0.00000	0.27	0.00000	0.27	0.00000	0.27	0.00000	0.27	0.00000
0.28	0.00000	0.28	0.00000	0.28	0.00000	0.28	0.00000	0.28	0.00000	0.28	0.00000
0.29	0.00000	0.29	0.00000	0.29	0.00000	0.29	0.00000	0.29	0.00000	0.29	0.00000
0.30	0.00000	0.30	0.00000	0.30	0.00000	0.30	0.00000	0.30	0.00000	0.30	0.00000
0.31	0.00000	0.31	0.00000	0.31	0.00000	0.31	0.00000	0.31	0.00000	0.31	0.00000
0.32	0.00000	0.32	0.00000	0.32	0.00000	0.32	0.00000	0.32	0.00000	0.32	0.00000
0.33	0.00000	0.33	0.00000	0.33	0.00000	0.33	0.00000	0.33	0.00000	0.33	0.00000
0.34	0.00000	0.34	0.00000	0.34	0.00000	0.34	0.00000	0.34	0.00000	0.34	0.00000
0.35	0.00000	0.35	0.00000	0.35	0.00000	0.35	0.00000	0.35	0.00000	0.35	0.00000
0.36	0.00000	0.36	0.00000	0.36	0.00000	0.36	0.00000	0.36	0.00000	0.36	0.00000
0.37	0.00000	0.37	0.00000	0.37	0.00000	0.37	0.00000	0.37	0.00000	0.37	0.00000
0.38	0.00000	0.38	0.00000	0.38	0.00000	0.38	0.00000	0.38	0.00000	0.38	0.00000
0.39	0.00000	0.39	0.00000	0.39	0.00000	0.39	0.00000	0.39	0.00000	0.39	0.00000
0.40	0.00000	0.40	0.00000	0.40	0.00000	0.40	0.00000	0.40	0.00000	0.40	0.00000
0.42	0.00000	0.42	0.00000	0.42	0.00000	0.42	0.00000	0.42	0.00000	0.42	0.00000
0.44	0.00000	0.44	0.00000	0.44	0.00000	0.44	0.00000	0.44	0.00000	0.44	0.00000
0.46	0.00000	0.46	0.00000	0.46	0.00000	0.46	0.00000	0.46	0.00000	0.46	0.00000
0.48	0.00000	0.48	0.00000	0.48	0.00000	0.48	0.00000	0.48	0.00000	0.48	0.00000
0.50	0.00000	0.50	0.00000	0.50	0.00000	0.50	0.00000	0.50	0.00000	0.50	0.00000
0.52	0.00000	0.52	0.00000	0.52	0.00000	0.52	0.00000	0.52	0.00000	0.52	0.00000
0.54	0.00000	0.54	0.00000	0.54	0.00000	0.54	0.00000	0.54	0.00000	0.54	0.00000
0.56	0.00000	0.56	0.00000	0.56	0.00000	0.56	0.00000	0.56	0.00000	0.56	0.00000
0.58	0.00000	0.58	0.00000	0.58	0.00000	0.58	0.00000	0.58	0.00000	0.58	0.00000
0.60	0.00000	0.60	0.00000	0.60	0.00000	0.60	0.00000	0.60	0.00000	0.60	0.00000
0.64	0.00000	0.64	0.00000	0.64	0.00000	0.64	0.00000	0.64	0.00000	0.64	0.00000
0.68	0.00000	0.68	0.00000	0.68	0.00000	0.68	0.00000	0.68	0.00000	0.68	0.00000
0.72	0.00000	0.72	0.00000	0.72	0.00000	0.72	0.00000	0.72	0.00000	0.72	0.00000
0.76	0.00000	0.76	0.00000	0.76	0.00000	0.76	0.00000	0.76	0.00000	0.76	0.00000
0.80	0.00000	0.80	0.00000	0.80	0.00000	0.80	0.00000	0.80	0.00000	0.80	0.00000
0.84	0.00000	0.84	0.00000	0.84	0.00000	0.84	0.00000	0.84	0.00000	0.84	0.00000
0.88	0.00000	0.88	0.00000	0.88	0.00000	0.88	0.00000	0.88	0.00000	0.88	0.00000
0.92	0.00000	0.92	0.00000	0.92	0.00000	0.92	0.00000	0.92	0.00000	0.92	0.00000
0.96	0.00000	0.96	0.00000	0.96	0.00000	0.96	0.00000	0.96	0.00000	0.96	0.00000
1.00	0.00000	1.00	0.00000	1.00	0.00000	1.00	0.00000	1.00	0.00000	1.00	0.00000
ST DEV	0.0505		0.0254		0.0315		0.0431		0.0256		0.0341

D I S T R I B U T I O N   F U N C T I O N   E S T I M A T E

FILE18
RUN 17

LRC TEST CURVED LOCOMOTIVE RUN 17 67 MPH DRIFT

3072. SCANS

G'S	VERT1	G'S	LONG1	G'S	LAT1	G'S	VERT2	G'S	LONG2	G'S	LAT2
-0.96	0.00000	-0.96	0.00000	-0.96	0.00000	-0.96	0.00000	-0.96	0.00000	-0.96	0.00000
-0.92	0.00000	-0.92	0.00000	-0.92	0.00000	-0.92	0.00000	-0.92	0.00000	-0.92	0.00000
-0.88	0.00000	-0.88	0.00000	-0.88	0.00000	-0.88	0.00000	-0.88	0.00000	-0.88	0.00000
-0.84	0.00000	-0.84	0.00000	-0.84	0.00000	-0.84	0.00000	-0.84	0.00000	-0.84	0.00000
-0.80	0.00000	-0.80	0.00000	-0.80	0.00000	-0.80	0.00000	-0.80	0.00000	-0.80	0.00000
-0.76	0.00000	-0.76	0.00000	-0.76	0.00000	-0.76	0.00000	-0.76	0.00000	-0.76	0.00000
-0.72	0.00000	-0.72	0.00000	-0.72	0.00000	-0.72	0.00000	-0.72	0.00000	-0.72	0.00000
-0.68	0.00000	-0.68	0.00000	-0.68	0.00000	-0.68	0.00000	-0.68	0.00000	-0.68	0.00000
-0.64	0.00000	-0.64	0.00000	-0.64	0.00000	-0.64	0.00000	-0.64	0.00000	-0.64	0.00000
-0.60	0.00000	-0.60	0.00000	-0.60	0.00000	-0.60	0.00000	-0.60	0.00000	-0.60	0.00000
-0.58	0.00000	-0.58	0.00000	-0.58	0.00000	-0.58	0.00000	-0.58	0.00000	-0.58	0.00000
-0.56	0.00000	-0.56	0.00000	-0.56	0.00000	-0.56	0.00000	-0.56	0.00000	-0.56	0.00000
-0.54	0.00000	-0.54	0.00000	-0.54	0.00000	-0.54	0.00000	-0.54	0.00000	-0.54	0.00000
-0.52	0.00000	-0.52	0.00000	-0.52	0.00000	-0.52	0.00000	-0.52	0.00000	-0.52	0.00000
-0.50	0.00000	-0.50	0.00000	-0.50	0.00000	-0.50	0.00000	-0.50	0.00000	-0.50	0.00000
-0.48	0.00000	-0.48	0.00000	-0.48	0.00000	-0.48	0.00000	-0.48	0.00000	-0.48	0.00000
-0.46	0.00000	-0.46	0.00000	-0.46	0.00000	-0.46	0.00000	-0.46	0.00000	-0.46	0.00000
-0.44	0.00000	-0.44	0.00000	-0.44	0.00000	-0.44	0.00000	-0.44	0.00000	-0.44	0.00000
-0.42	0.00000	-0.42	0.00000	-0.42	0.00000	-0.42	0.00000	-0.42	0.00000	-0.42	0.00000
-0.40	0.00000	-0.40	0.00000	-0.40	0.00000	-0.40	0.00000	-0.40	0.00000	-0.40	0.00000
-0.39	0.00000	-0.39	0.00000	-0.39	0.00000	-0.39	0.00000	-0.39	0.00000	-0.39	0.00000
-0.38	0.00000	-0.38	0.00000	-0.38	0.00000	-0.38	0.00000	-0.38	0.00000	-0.38	0.00000
-0.37	0.00000	-0.37	0.00000	-0.37	0.00000	-0.37	0.00000	-0.37	0.00000	-0.37	0.00000
-0.36	0.00000	-0.36	0.00000	-0.36	0.00000	-0.36	0.00000	-0.36	0.00000	-0.36	0.00000
-0.35	0.00000	-0.35	0.00000	-0.35	0.00000	-0.35	0.00000	-0.35	0.00000	-0.35	0.00000
-0.34	0.00000	-0.34	0.00000	-0.34	0.00000	-0.34	0.00000	-0.34	0.00000	-0.34	0.00000
-0.33	0.00000	-0.33	0.00000	-0.33	0.00000	-0.33	0.00000	-0.33	0.00000	-0.33	0.00000
-0.32	0.00000	-0.32	0.00000	-0.32	0.00000	-0.32	0.00000	-0.32	0.00000	-0.32	0.00000
-0.31	0.00000	-0.31	0.00000	-0.31	0.00000	-0.31	0.00000	-0.31	0.00000	-0.31	0.00000
-0.30	0.00000	-0.30	0.00000	-0.30	0.00000	-0.30	0.00000	-0.30	0.00000	-0.30	0.00000
-0.29	0.00000	-0.29	0.00000	-0.29	0.00000	-0.29	0.00000	-0.29	0.00000	-0.29	0.00000
-0.28	0.00000	-0.28	0.00000	-0.28	0.00000	-0.28	0.00000	-0.28	0.00000	-0.28	0.00000
-0.27	0.00000	-0.27	0.00000	-0.27	0.00000	-0.27	0.00000	-0.27	0.00000	-0.27	0.00000
-0.26	0.00000	-0.26	0.00000	-0.26	0.00000	-0.26	0.00000	-0.26	0.00000	-0.26	0.00000
-0.25	0.00033	-0.25	0.00000	-0.25	0.00000	-0.25	0.00000	-0.25	0.00000	-0.25	0.00000
-0.24	0.00065	-0.24	0.00000	-0.24	0.00000	-0.24	0.00000	-0.24	0.00000	-0.24	0.00000
-0.23	0.00130	-0.23	0.00000	-0.23	0.00000	-0.23	0.00000	-0.23	0.00000	-0.23	0.00000
-0.22	0.00163	-0.22	0.00000	-0.22	0.00000	-0.22	0.00000	-0.22	0.00000	-0.22	0.00000
-0.21	0.00195	-0.21	0.00000	-0.21	0.00000	-0.21	0.00000	-0.21	0.00000	-0.21	0.00000
-0.20	0.00293	-0.20	0.00000	-0.20	0.00000	-0.20	0.00000	-0.20	0.00000	-0.20	0.00000
-0.19	0.00326	-0.19	0.00000	-0.19	0.00000	-0.19	0.00000	-0.19	0.00000	-0.19	0.00000
-0.18	0.00391	-0.18	0.00000	-0.18	0.00000	-0.18	0.00000	-0.18	0.00000	-0.18	0.00000
-0.17	0.00391	-0.17	0.00000	-0.17	0.00000	-0.17	0.00033	-0.17	0.00000	-0.17	0.00000
-0.16	0.00391	-0.16	0.00000	-0.16	0.00000	-0.16	0.00130	-0.16	0.00000	-0.16	0.00000
-0.15	0.00456	-0.15	0.00000	-0.15	0.00000	-0.15	0.00195	-0.15	0.00000	-0.15	0.00000
-0.14	0.00618	-0.14	0.00000	-0.14	0.00000	-0.14	0.00228	-0.14	0.00000	-0.14	0.00000
-0.13	0.00846	-0.13	0.00000	-0.13	0.00000	-0.13	0.00423	-0.13	0.00000	-0.13	0.00000
-0.12	0.01204	-0.12	0.00000	-0.12	0.00000	-0.12	0.00553	-0.12	0.00000	-0.12	0.00000
-0.11	0.01660	-0.11	0.00000	-0.11	0.00000	-0.11	0.00749	-0.11	0.00000	-0.11	0.00000
-0.10	0.02344	-0.10	0.00000	-0.10	0.00000	-0.10	0.01139	-0.10	0.00000	-0.10	0.00033
-0.09	0.03874	-0.09	0.00000	-0.09	0.00000	-0.09	0.01790	-0.09	0.00033	-0.09	0.00326
-0.08	0.05534	-0.08	0.00000	-0.08	0.00684	-0.08	0.02767	-0.08	0.00130	-0.08	0.00879
-0.07	0.08236	-0.07	0.00228	-0.07	0.01758	-0.07	0.04915	-0.07	0.00391	-0.07	0.02148
-0.06	0.10937	-0.06	0.00781	-0.06	0.03223	-0.06	0.07552	-0.06	0.01139	-0.06	0.04460
-0.05	0.14453	-0.05	0.02409	-0.05	0.06413	-0.05	0.11328	-0.05	0.02767	-0.05	0.06445
-0.04	0.19531	-0.04	0.05469	-0.04	0.10286	-0.04	0.16960	-0.04	0.06022	-0.04	0.11426
-0.03	0.25716	-0.03	0.11328	-0.03	0.16178	-0.03	0.23145	-0.03	0.12109	-0.03	0.18262
-0.02	0.32682	-0.02	0.23177	-0.02	0.25163	-0.02	0.31510	-0.02	0.20475	-0.02	0.27572
-0.01	[illegible]	-0.01	0.37370	-0.01	0.37728	-0.01	0.41146	-0.01	0.32585	-0.01	0.37891

DISTRIBUTION FUNCTION ESTIMATE

-0.00	0.48568	-0.00	0.52214	-0.00	0.50130	-0.00	0.50977	-0.00	0.48047	-0.00	0.50228
0.01	0.57031	0.01	0.67318	0.01	0.64095	0.01	0.59993	0.01	0.63770	0.01	0.62793
0.02	0.66276	0.02	0.80078	0.02	0.76367	0.02	0.69596	0.02	0.77930	0.02	0.74219
0.03	0.73079	0.03	0.88932	0.03	0.83659	0.03	0.76823	0.03	0.88509	0.03	0.83073
0.04	0.79883	0.04	0.94792	0.04	0.89779	0.04	0.83854	0.04	0.94694	0.04	0.89421
0.05	0.85937	0.05	0.97656	0.05	0.93945	0.05	0.88314	0.05	0.98112	0.05	0.93555
0.06	0.89779	0.06	0.98763	0.06	0.97103	0.06	0.92285	0.06	0.99219	0.06	0.96126
0.07	0.92969	0.07	0.99642	0.07	0.98665	0.07	0.94889	0.07	0.99805	0.07	0.97689
0.08	0.95410	0.08	0.99902	0.08	0.99642	0.08	0.96842	0.08	0.99935	0.08	0.98470
0.09	0.96875	0.09	1.00000	0.09	0.99935	0.09	0.97884	0.09	1.00000	0.09	0.99089
0.10	0.98079	0.10	1.00000	0.10	1.00000	0.10	0.98535	0.10	1.00000	0.10	0.99382
0.11	0.98763	0.11	1.00000	0.11	1.00000	0.11	0.99284	0.11	1.00000	0.11	0.99577
0.12	0.99056	0.12	1.00000	0.12	1.00000	0.12	0.99577	0.12	1.00000	0.12	0.99837
0.13	0.99349	0.13	1.00000	0.13	1.00000	0.13	0.99707	0.13	1.00000	0.13	0.99967
0.14	0.99447	0.14	1.00000	0.14	1.00000	0.14	0.99837	0.14	1.00000	0.14	1.00000
0.15	0.99544	0.15	1.00000	0.15	1.00000	0.15	0.99967	0.15	1.00000	0.15	1.00000
0.16	0.99642	0.16	1.00000	0.16	1.00000	0.16	1.00000	0.16	1.00000	0.16	1.00000
0.17	0.99707	0.17	1.00000	0.17	1.00000	0.17	1.00000	0.17	1.00000	0.17	1.00000
0.18	0.99740	0.18	1.00000	0.18	1.00000	0.18	1.00000	0.18	1.00000	0.18	1.00000
0.19	0.99935	0.19	1.00000	0.19	1.00000	0.19	1.00000	0.19	1.00000	0.19	1.00000
0.20	0.99935	0.20	1.00000	0.20	1.00000	0.20	1.00000	0.20	1.00000	0.20	1.00000
0.21	1.00000	0.21	1.00000	0.21	1.00000	0.21	1.00000	0.21	1.00000	0.21	1.00000
0.22	1.00000	0.22	1.00000	0.22	1.00000	0.22	1.00000	0.22	1.00000	0.22	1.00000
0.23	1.00000	0.23	1.00000	0.23	1.00000	0.23	1.00000	0.23	1.00000	0.23	1.00000
0.24	1.00000	0.24	1.00000	0.24	1.00000	0.24	1.00000	0.24	1.00000	0.24	1.00000
0.25	1.00000	0.25	1.00000	0.25	1.00000	0.25	1.00000	0.25	1.00000	0.25	1.00000
0.26	1.00000	0.26	1.00000	0.26	1.00000	0.26	1.00000	0.26	1.00000	0.26	1.00000
0.27	1.00000	0.27	1.00000	0.27	1.00000	0.27	1.00000	0.27	1.00000	0.27	1.00000
0.28	1.00000	0.28	1.00000	0.28	1.00000	0.28	1.00000	0.28	1.00000	0.28	1.00000
0.29	1.00000	0.29	1.00000	0.29	1.00000	0.29	1.00000	0.29	1.00000	0.29	1.00000
0.30	1.00000	0.30	1.00000	0.30	1.00000	0.30	1.00000	0.30	1.00000	0.30	1.00000
0.31	1.00000	0.31	1.00000	0.31	1.00000	0.31	1.00000	0.31	1.00000	0.31	1.00000
0.32	1.00000	0.32	1.00000	0.32	1.00000	0.32	1.00000	0.32	1.00000	0.32	1.00000
0.33	1.00000	0.33	1.00000	0.33	1.00000	0.33	1.00000	0.33	1.00000	0.33	1.00000
0.34	1.00000	0.34	1.00000	0.34	1.00000	0.34	1.00000	0.34	1.00000	0.34	1.00000
0.35	1.00000	0.35	1.00000	0.35	1.00000	0.35	1.00000	0.35	1.00000	0.35	1.00000
0.36	1.00000	0.36	1.00000	0.36	1.00000	0.36	1.00000	0.36	1.00000	0.36	1.00000
0.37	1.00000	0.37	1.00000	0.37	1.00000	0.37	1.00000	0.37	1.00000	0.37	1.00000
0.38	1.00000	0.38	1.00000	0.38	1.00000	0.38	1.00000	0.38	1.00000	0.38	1.00000
0.39	1.00000	0.39	1.00000	0.39	1.00000	0.39	1.00000	0.39	1.00000	0.39	1.00000
0.40	1.00000	0.40	1.00000	0.40	1.00000	0.40	1.00000	0.40	1.00000	0.40	1.00000
0.42	1.00000	0.42	1.00000	0.42	1.00000	0.42	1.00000	0.42	1.00000	0.42	1.00000
0.44	1.00000	0.44	1.00000	0.44	1.00000	0.44	1.00000	0.44	1.00000	0.44	1.00000
0.46	1.00000	0.46	1.00000	0.46	1.00000	0.46	1.00000	0.46	1.00000	0.46	1.00000
0.48	1.00000	0.48	1.00000	0.48	1.00000	0.48	1.00000	0.48	1.00000	0.48	1.00000
0.50	1.00000	0.50	1.00000	0.50	1.00000	0.50	1.00000	0.50	1.00000	0.50	1.00000
0.52	1.00000	0.52	1.00000	0.52	1.00000	0.52	1.00000	0.52	1.00000	0.52	1.00000
0.54	1.00000	0.54	1.00000	0.54	1.00000	0.54	1.00000	0.54	1.00000	0.54	1.00000
0.56	1.00000	0.56	1.00000	0.56	1.00000	0.56	1.00000	0.56	1.00000	0.56	1.00000
0.58	1.00000	0.58	1.00000	0.58	1.00000	0.58	1.00000	0.58	1.00000	0.58	1.00000
0.60	1.00000	0.60	1.00000	0.60	1.00000	0.60	1.00000	0.60	1.00000	0.60	1.00000
0.64	1.00000	0.64	1.00000	0.64	1.00000	0.64	1.00000	0.64	1.00000	0.64	1.00000
0.68	1.00000	0.68	1.00000	0.68	1.00000	0.68	1.00000	0.68	1.00000	0.68	1.00000
0.72	1.00000	0.72	1.00000	0.72	1.00000	0.72	1.00000	0.72	1.00000	0.72	1.00000
0.76	1.00000	0.76	1.00000	0.76	1.00000	0.76	1.00000	0.76	1.00000	0.76	1.00000
0.80	1.00000	0.80	1.00000	0.80	1.00000	0.80	1.00000	0.80	1.00000	0.80	1.00000
0.84	1.00000	0.84	1.00000	0.84	1.00000	0.84	1.00000	0.84	1.00000	0.84	1.00000
0.88	1.00000	0.88	1.00000	0.88	1.00000	0.88	1.00000	0.88	1.00000	0.88	1.00000
0.92	1.00000	0.92	1.00000	0.92	1.00000	0.92	1.00000	0.92	1.00000	0.92	1.00000
0.96	1.00000	0.96	1.00000	0.96	1.00000	0.96	1.00000	0.96	1.00000	0.96	1.00000
1.00	1.00000	1.00	1.00000	1.00	1.00000	1.00	1.00000	1.00	1.00000	1.00	1.00000
	[illegible]		0.0254		0.0315		0.0431		0.0256		0.0341

1/3 OCTAVE BANDS - AVERAGE RMS ACCELERATION

LRC TEST CURVED LOCOMOTIVE RUN 17 67 MPH DRIFT

RUN 17

CENTER FREQ		VERT1 G'S	LONG1 G'S	LAT1 G'S
1.0 HZ	LB	0.00000	0.00000	0.00229
	EV	0.01207	0.00133	0.01006
	UB	0.01758	0.00196	0.01404
1.3 HZ	LB	0.00978	0.00091	0.00873
	EV	0.02013	0.00157	0.01391
	UB	0.02673	0.00203	0.01764
1.6 HZ	LB	0.01523	0.00110	0.00951
	EV	0.02880	0.00155	0.01563
	UB	0.03778	0.00189	0.01994
2.0 HZ	LB	0.00951	0.00077	0.00402
	EV	0.01520	0.00115	0.01008
	UB	0.01929	0.00143	0.01368
2.5 HZ	LB	0.00852	0.00078	0.00633
	EV	0.01104	0.00150	0.00960
	UB	0.01309	0.00197	0.01202
3.1 HZ	LB	0.00666	0.00144	0.00379
	EV	0.00915	0.00176	0.00756
	UB	0.01109	0.00203	0.00999
4.0 HZ	LB	0.00382	0.00110	0.00204
	EV	0.00534	0.00264	0.00558
	UB	0.00651	0.00357	0.00762
5.0 HZ	LB	0.00454	0.00179	0.00255
	EV	0.01434	0.00813	0.00410
	UB	0.01976	0.01136	0.00521

CENTER FREQ		VERT1 G'S	LONG1 G'S	LAT1 G'S
6.3 HZ	LB	0.00784	0.00719	0.00204
	EV	0.01277	0.00940	0.00313
	UB	0.01626	0.01118	0.00393
8.0 HZ	LB	0.01013	0.01229	0.00231
	EV	0.01205	0.01879	0.00293
	UB	0.01371	0.02356	0.00344
10.0 HZ	LB	0.00431	0.00543	0.00347
	EV	0.00508	0.00724	0.00417
	UB	0.00574	0.00867	0.00477
12.5 HZ	LB	0.00451	0.00323	0.00419
	EV	0.00560	0.00404	0.00530
	UB	0.00651	0.00471	0.00622
16.0 HZ	LB	0.00422	0.00270	0.00263
	EV	0.00479	0.00336	0.00291
	UB	0.00530	0.00391	0.00317
20.0 HZ	LB	0.00411	0.00201	0.00180
	EV	0.00512	0.00243	0.00216
	UB	0.00596	0.00279	0.00247
25.0 HZ	LB	0.00795	0.00305	0.00089
	EV	0.00851	0.00333	0.00138
	UB	0.00904	0.00360	0.00174
31.5 HZ	LB	0.00349	0.00193	0.00202
	EV	0.00403	0.00212	0.00213
	UB	0.00451	0.00230	0.00224

1/3 OCTAVE BANDS - AVERAGE RMS ACCELERATION

LRC TEST CURVED LOCOMOTIVE RUN 17 67 MPH DRIFT

RUN 17

CENTER FREQ		VERT2 G'S	LONG2 G'S	LAT2 G'S
1.0 HZ	LB	0.00369	0.00067	0.00000
	EV	0.00809	0.00147	0.00960
	UB	0.01083	0.00197	0.01397
1.3 HZ	LB	0.00388	0.00062	0.00000
	EV	0.01156	0.00170	0.01419
	UB	0.01589	0.00232	0.02009
1.6 HZ	LB	0.00780	0.00099	0.00785
	EV	0.01879	0.00229	0.01373
	UB	0.02541	0.00309	0.01777
2.0 HZ	LB	0.00810	0.00081	0.00398
	EV	0.01160	0.00177	0.00884
	UB	0.01426	0.00238	0.01185
2.5 HZ	LB	0.00755	0.00110	0.00755
	EV	0.01151	0.00181	0.01146
	UB	0.01442	0.00231	0.01434
3.1 HZ	LB	0.00803	0.00142	0.00109
	EV	0.00982	0.00193	0.00765
	UB	0.01133	0.00233	0.01076
4.0 HZ	LB	0.00451	0.00160	0.00000
	EV	0.00643	0.00294	0.00628
	UB	0.00790	0.00384	0.00892
5.0 HZ	LB	0.00166	0.00409	0.00290
	EV	0.01168	0.00593	0.00393
	UB	0.01643	0.00732	0.00474

CENTER FREQ		VERT2 G'S	LONG2 G'S	LAT2 G'S
6.3 HZ	LB	0.00532	0.00572	0.00243
	EV	0.00831	0.00796	0.00302
	UB	0.01048	0.00970	0.00351
8.0 HZ	LB	0.00834	0.01329	0.00179
	EV	0.01000	0.01993	0.00409
	UB	0.01142	0.02486	0.00551
10.0 HZ	LB	0.00553	0.00507	0.00458
	EV	0.00666	0.00701	0.00500
	UB	0.00762	0.00852	0.00538
12.5 HZ	LB	0.00909	0.00320	0.00358
	EV	0.01010	0.00407	0.00432
	UB	0.01101	0.00478	0.00494
16.0 HZ	LB	0.00720	0.00299	0.00238
	EV	0.00766	0.00361	0.00261
	UB	0.00809	0.00415	0.00281
20.0 HZ	LB	0.00585	0.00228	0.00205
	EV	0.00706	0.00261	0.00241
	UB	0.00808	0.00289	0.00272
25.0 HZ	LB	0.00813	0.00361	0.00259
	EV	0.00950	0.00394	0.00288
	UB	0.01070	0.00425	0.00314
31.5 HZ	LB	0.00480	0.00200	0.00219
	EV	0.00539	0.00220	0.00244
	UB	0.00593	0.00239	0.00266

TIME LIMITS - REDUCED COMFORT

LRC TEST CURVED LOCOMOTIVE RUN 17 67 MPH DRIFT RU

N 17

CENTER FREQ		LONG1	LAT1	VERT1
1.0 HZ	LB	24.0	24.0	24.0
	EV	24.0	5.0	13.3
	UB	24.0	3.0	8.4
1.3 HZ	LB	24.0	6.1	14.9
	EV	24.0	3.1	6.1
	UB	24.0	2.1	4.2
1.6 HZ	LB	24.0	5.4	7.5
	EV	24.0	2.6	3.3
	UB	24.0	1.7	2.2
2.0 HZ	LB	24.0	17.7	11.7
	EV	24.0	5.0	6.5
	UB	24.0	3.2	4.8
2.5 HZ	LB	24.0	13.0	11.6
	EV	24.0	7.4	8.4
	UB	24.0	5.4	6.8
3.1 HZ	LB	24.0	24.0	13.6
	EV	24.0	14.0	9.2
	UB	24.0	9.6	7.3
4.0 HZ	LB	24.0	24.0	23.1
	EV	24.0	24.0	15.5
	UB	24.0	18.9	12.2
5.0 HZ	LB	24.0	24.0	18.8
	EV	23.6	24.0	4.5
	UB	15.1	24.0	2.9

CENTER FREQ		LONG1	LAT1	VERT1
6.3 HZ	LB	24.0	24.0	9.7
	EV	24.0	24.0	5.2
	UB	21.0	24.0	3.8
8.0 HZ	LB	24.0	24.0	7.1
	EV	14.2	24.0	5.7
	UB	10.4	24.0	4.8
10.0 HZ	LB	24.0	24.0	24.0
	EV	24.0	24.0	21.7
	UB	24.0	24.0	18.7
12.5 HZ	LB	24.0	24.0	24.0
	EV	24.0	24.0	24.0
	UB	24.0	24.0	21.2
16.0 HZ	LB	24.0	24.0	24.0
	EV	24.0	24.0	24.0
	UB	24.0	24.0	24.0
20.0 HZ	LB	24.0	24.0	24.0
	EV	24.0	24.0	24.0
	UB	24.0	24.0	24.0
25.0 HZ	LB	24.0	24.0	24.0
	EV	24.0	24.0	24.0
	UB	24.0	24.0	24.0
31.5 HZ	LB	24.0	24.0	24.0
	EV	24.0	24.0	24.0
	UB	24.0	24.0	24.0

MINIMA

	LONG1	LAT1	VERT1
EXPOSURE TIME (HRS):	14.2	2.6	3.3
CENTER FREQ (HZ):	8.0	1.6	1.6

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

FREQ(HZ)	VERT1	LONG1	LAT1	VERT2	LONG2	LAT2
0.25	-41.3253	-44.5454	-34.2082	-43.5968	-43.6782	-32.6700
0.50	-43.4930	-46.9835	-35.2231	-39.3661	-45.7663	-31.8425
0.75	-37.4158	-50.4931	-37.1056	-36.4959	-50.2317	-30.5050
1.00	-32.3422	-51.4886	-33.9268	-35.8219	-50.6151	-34.3323
1.25	-29.3613	-50.6768	-32.0770	-34.6325	-50.5712	-31.6460
1.50	-25.1178	-50.5933	-29.8682	-28.9581	-47.3577	-30.9554
1.75	-29.3128	-54.4231	-37.7647	-32.5680	-50.4411	-39.1896
2.00	-35.1914	-56.8876	-36.4187	-37.1128	-51.8916	-37.9829
2.25	-34.6714	-54.0741	-36.0658	-35.6679	-52.5461	-36.3052
2.50	-36.1440	-53.8389	-36.9745	-35.4769	-52.4544	-34.5779
2.75	-41.1749	-54.4775	-43.6670	-38.8783	-52.3928	-41.9526
3.00	-40.7008	-55.4669	-40.4362	-39.6478	-53.9003	-41.1008
3.25	-38.8283	-52.8823	-40.1557	-39.6761	-52.8177	-39.5215
3.50	-38.4762	-52.9711	-43.5805	-37.0795	-52.3297	-43.8786
3.75	-44.3362	-51.2274	-44.0338	-42.3504	-50.4870	-44.6754
4.00	-48.7278	-49.4048	-42.6323	-46.3020	-49.2297	-41.0070
4.25	-48.3919	-52.7997	-48.9915	-46.6660	-51.3996	-45.5030
4.50	-47.2947	-52.0866	-48.7480	-50.1415	-48.6323	-49.3757
4.75	-46.3071	-47.1556	-48.6257	-47.6825	-44.9882	-47.7713
5.00	-35.4889	-40.9581	-48.5326	-37.1900	-42.4756	-47.6950
5.25	-34.3751	-39.3336	-48.1827	-36.0835	-45.0483	-50.0482
5.50	-38.5653	-43.5272	-48.0377	-40.7265	-49.1683	-49.7604
5.75	-39.3227	-43.5853	-50.7147	-41.8025	-46.6812	-51.2544
6.00	-38.1557	-43.9415	-51.0734	-44.1142	-47.0026	-51.3015
6.25	-38.6985	-42.8238	-50.1022	-43.6222	-46.1833	-51.6426
6.50	-38.8205	-42.0832	-54.7297	-43.8336	-44.6711	-53.9325
6.75	-40.6597	-40.2943	-54.9203	-43.4808	-40.1105	-53.8859
7.00	-44.2333	-41.1194	-50.9029	-42.8005	-41.5109	-50.8687
7.25	-38.5805	-35.7688	-52.0198	-40.8011	-35.3387	-52.3042
7.50	-41.3818	-38.6969	-50.5125	-46.5336	-37.6382	-49.8503
7.75	-36.3117	-32.4074	-52.7169	-39.4462	-31.8344	-46.5719
8.00	-42.4711	-38.4369	-58.1624	-42.2708	-37.7358	-54.4399
8.25	-44.3758	-39.4980	-54.4176	-43.1816	-39.0061	-48.5476
8.50	-47.7341	-39.9800	-57.2318	-44.1534	-40.1456	-52.4272
8.75	-47.7127	-42.0677	-54.2079	-46.4845	-42.2015	-55.2647
9.00	-50.8723	-45.8518	-50.2406	-48.4446	-45.6217	-52.2932
9.25	-46.9672	-46.0124	-51.0395	-49.4704	-46.1691	-52.8421
9.50	-49.5110	-45.7206	-51.9716	-49.0994	-47.1444	-50.8141
9.75	-47.1780	-41.3322	-53.2160	-42.9798	-41.6675	-48.8060
10.00	-49.5650	-47.6123	-54.5427	-46.5673	-47.4612	-49.7022
10.25	-49.4691	-48.8777	-51.5418	-46.7544	-48.9885	-49.3691
10.50	-56.0880	-50.2061	-52.2800	-51.3828	-50.2294	-48.9737
10.75	-47.9014	-53.5912	-50.5224	-48.2182	-51.2298	-48.3346
11.00	-55.5672	-48.4647	-50.4486	-48.2727	-49.6100	-50.8345
11.25	-53.2023	-50.5112	-46.8987	-45.7289	-50.8031	-45.8653
11.50	-50.7652	-51.4958	-46.3585	-45.4350	-51.8468	-46.9810
11.75	-45.1216	-51.0159	-47.7399	-41.8131	-50.3230	-49.6650
12.00	-49.1748	-51.7070	-50.2080	-43.6064	-51.2327	-51.9010
12.25	-48.2979	-51.8146	-49.0902	-41.7599	-52.0371	-51.5151
12.50	-4[illegible].8206	-50.7782	-48.5112	-41.0582	-51.3087	-53.1699
12.75	-48.7449	-51.0226	-51.3934	-43.0706	-50.1601	-54.7126
13.00	-51.6817	-54.2172	-51.9280	-46.9183	-55.6872	-56.4282
13.25	-51.8339	-57.5375	-55.6690	-48.3499	-58.2392	-61.2657
13.50	-52.3851	-53.6201	-54.6263	-50.4128	-53.2945	-57.6194

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

FILE18 LRC TEST CURVED LOCOMOTIVE RUN 17 67 MPH DRIFT
RUN 17

	LONG1 G'S	LAT1 G'S	VERT1 G'S
STANDARD DEVIATION	.254E-01	0.032	0.051
95 PER CENT LEVEL	0.050	0.064	0.097
99 PER CENT LEVEL	0.067	0.080	0.147

	HOURS	HOURS	HOURS
MINIMUM EXPOSURE TIME (REDUCED COMFORT)	14.2	2.6	3.3
	HZ	HZ	HZ
CENTER FREQUENCY BAND	8.0	1.6	1.6

	HOURS	HOURS	HOURS
ALTERNATE METHOD EXPOSURE TIME (REDUCED COMFORT)	7.5	1.0	1.1

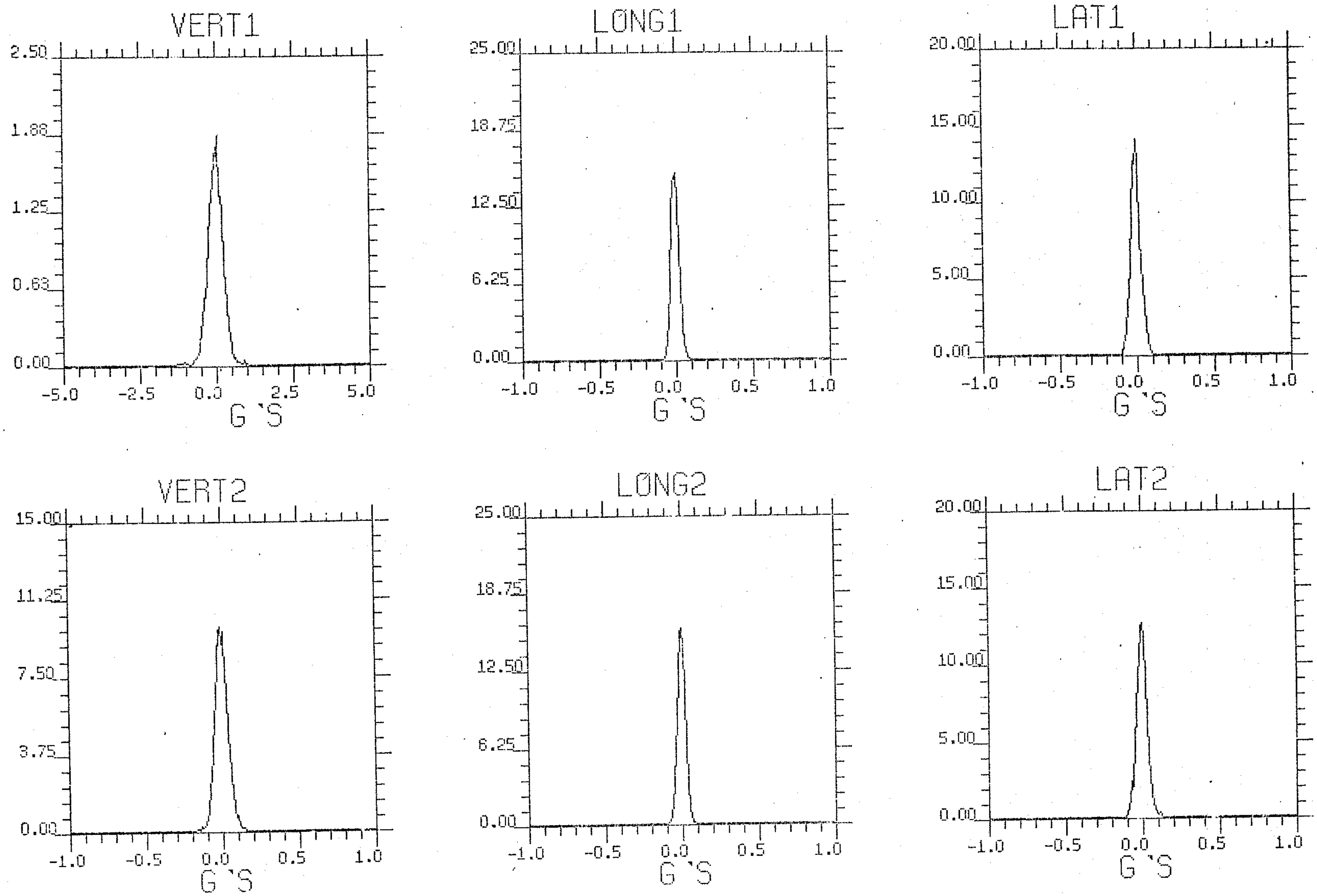
WZ RATING	LAT	2.5	FAIR
WZ RATING	VERT	2.8	ADEQUATE — FAIR

T I M E   P R O C E S S E D   24   S E C O N D S

PROBABILITY DENSITY ESTIMATE

LRC TEST CURVED LOCOMOTIVE RUN 17 67 MPH DRIFT

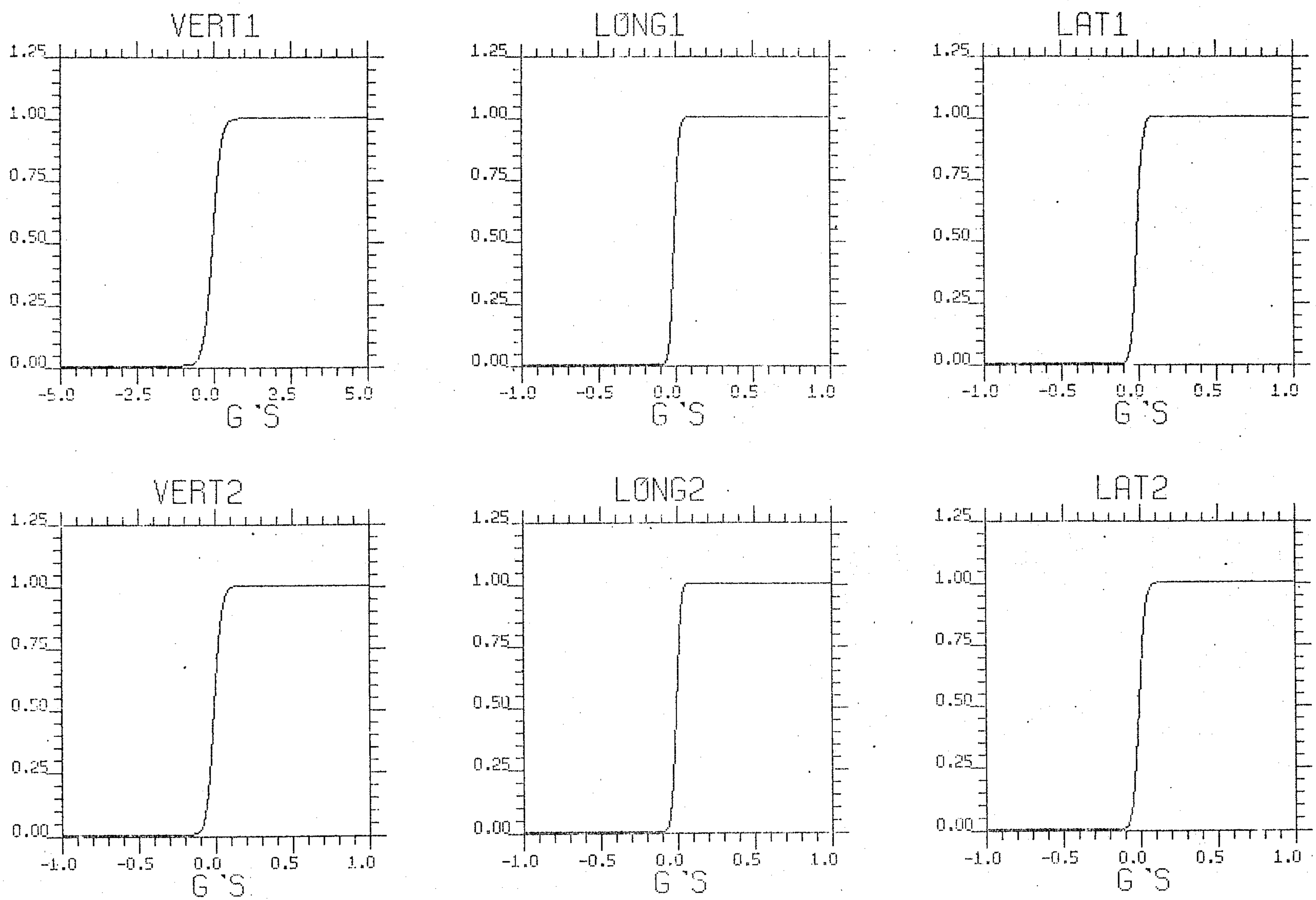
RUN 17

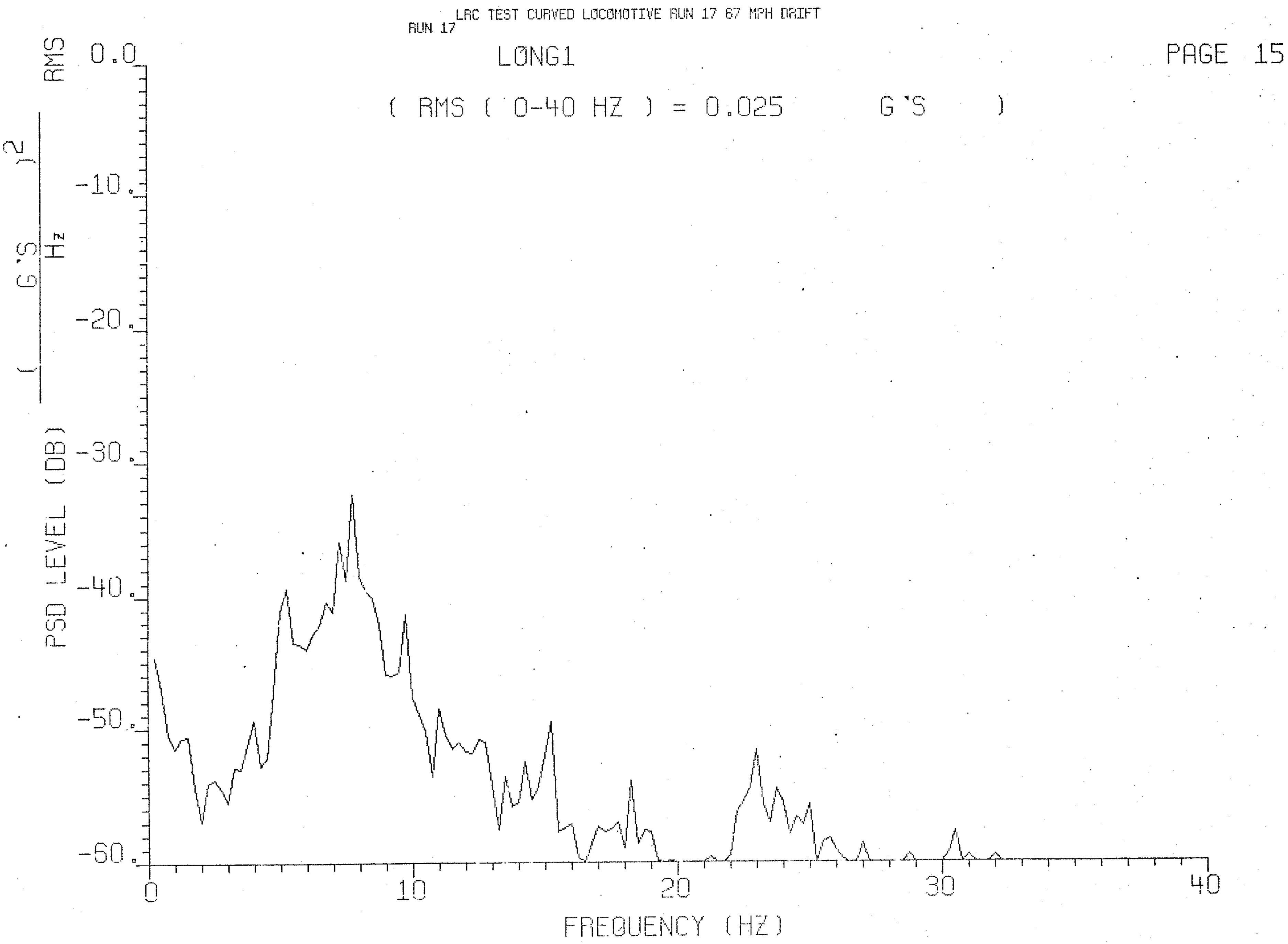


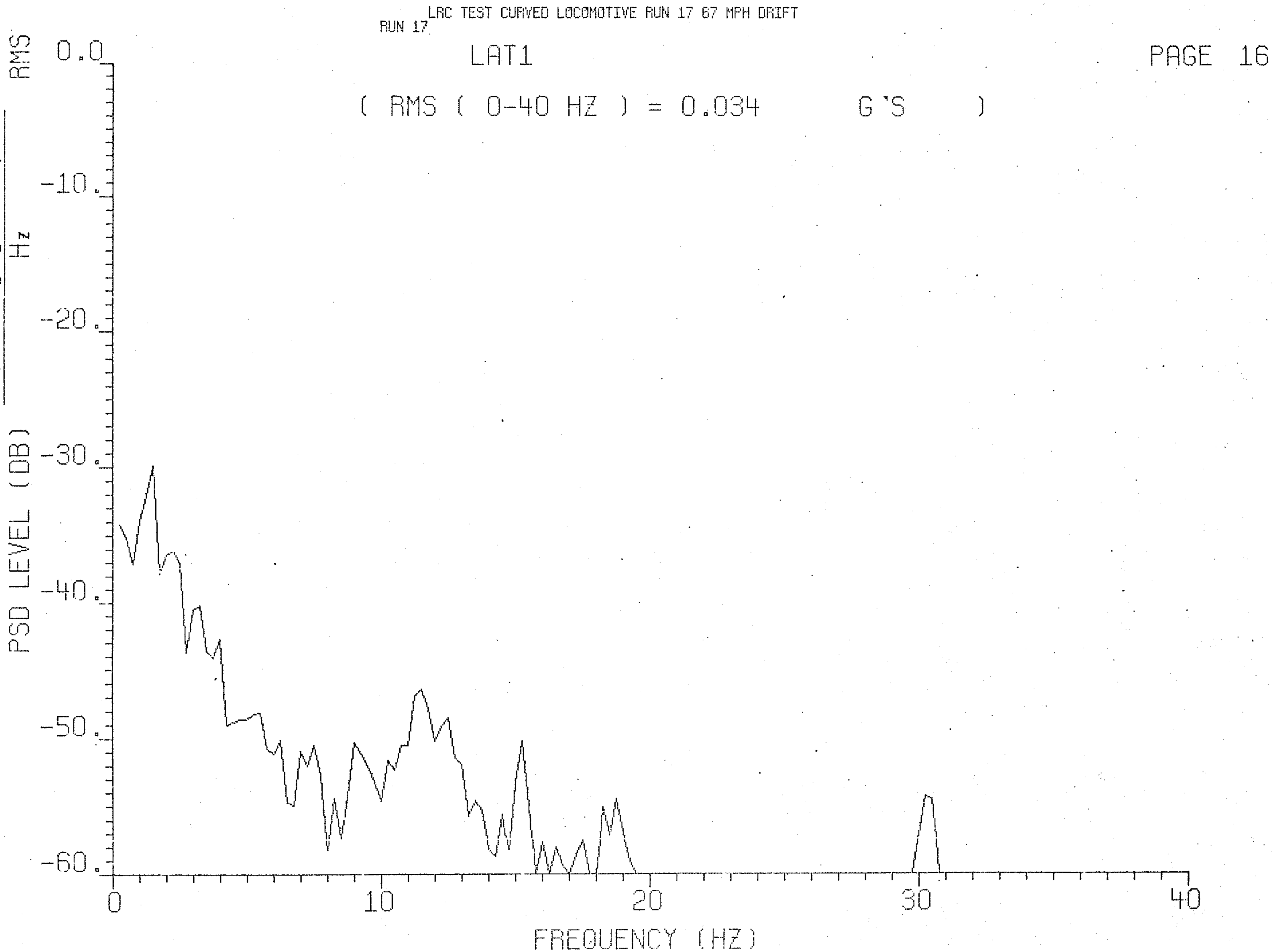
DISTRIBUTION FUNCTION ESTIMATE

LRC TEST CURVED LOCOMOTIVE RUN 17 67 MPH DRIFT

RUN 17




RUN 17
LRC TEST CURVED LOCOMOTIVE RUN 17 67 MPH DRIFT
LØNG1
PAGE 15
(RMS (0-40 HZ) = 0.025 G'S)
RMS
(G'S / Hz)²
PSD LEVEL (DB)
0.0
-10.
-20.
-30.
-40.
-50.
-60.
0
10
20
30
40
FREQUENCY (HZ)

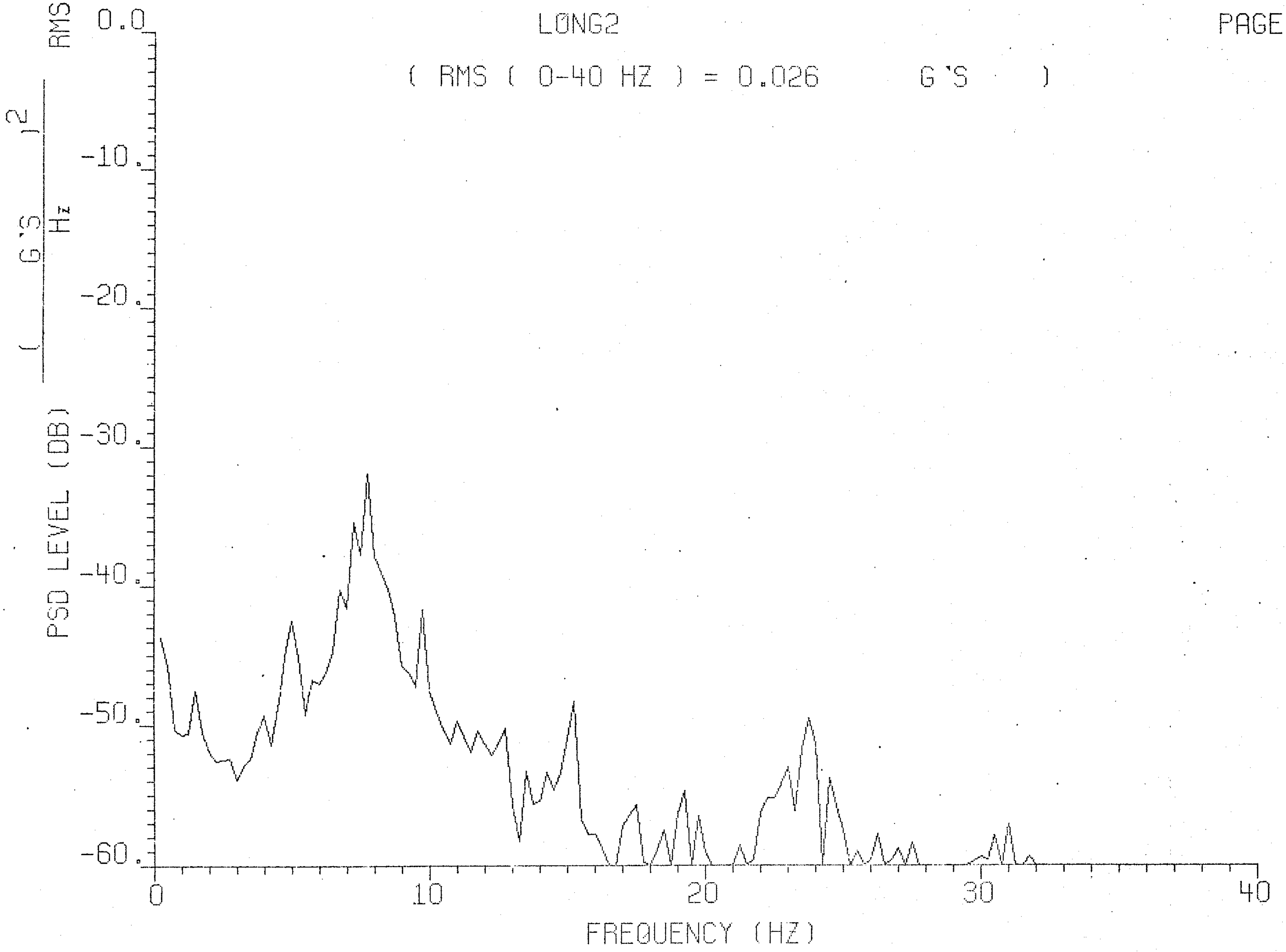


LRC TEST CURVED LOCOMOTIVE RUN 17 67 MPH DRIFT
RUN 17
LAT1
PAGE 16
(RMS (0-40 HZ) = 0.034 G'S)
RMS
(G'S)² / Hz
PSD LEVEL (DB)
0.0
-10.
-20.
-30.
-40.
-50.
-60.
0
10
20
30
40
FREQUENCY (HZ)

RUN 17 LRC TEST CURVED LOCOMOTIVE RUN 17 67 MPH DRIFT

LØNG2

(RMS (0-40 HZ) = 0.026 G'S)

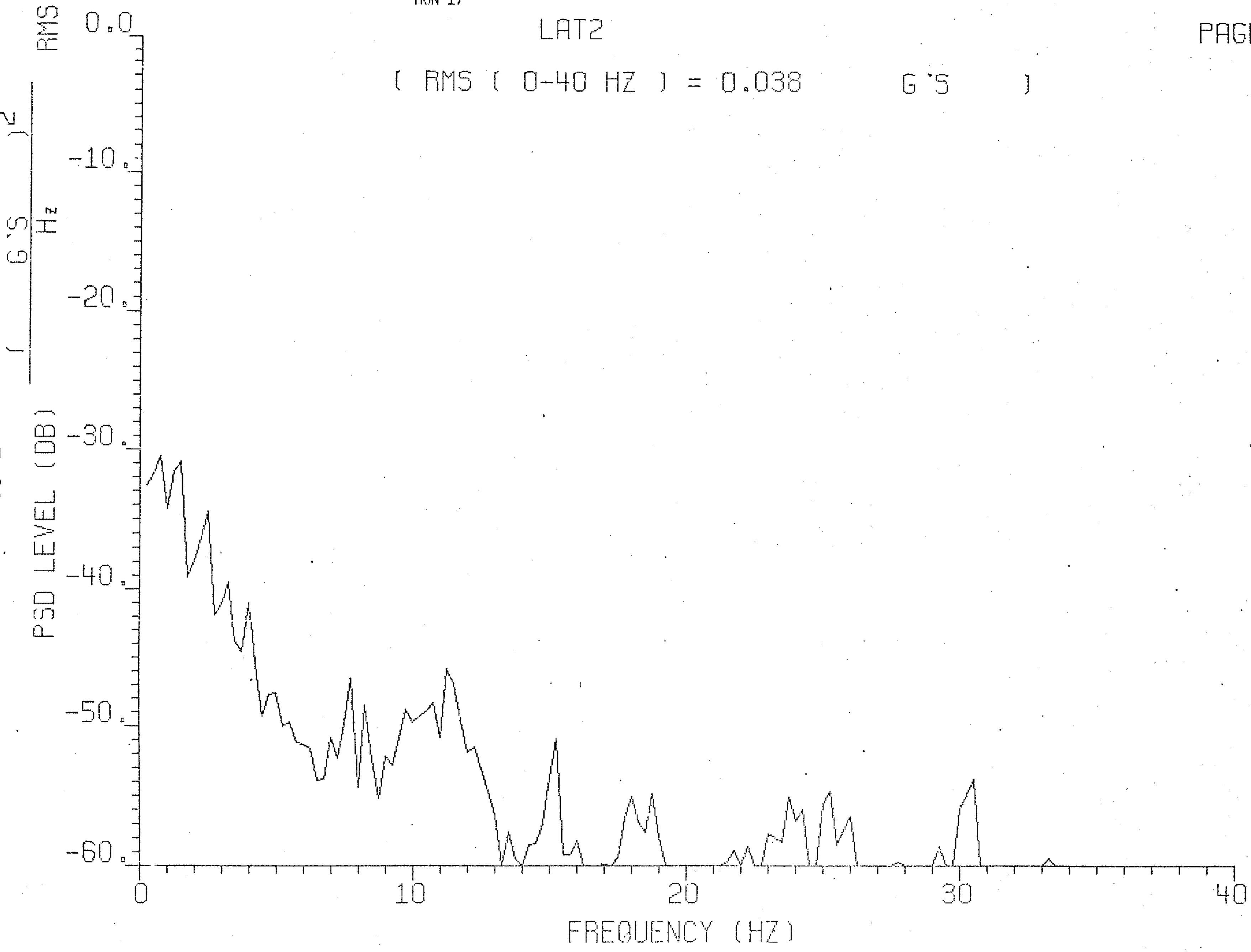


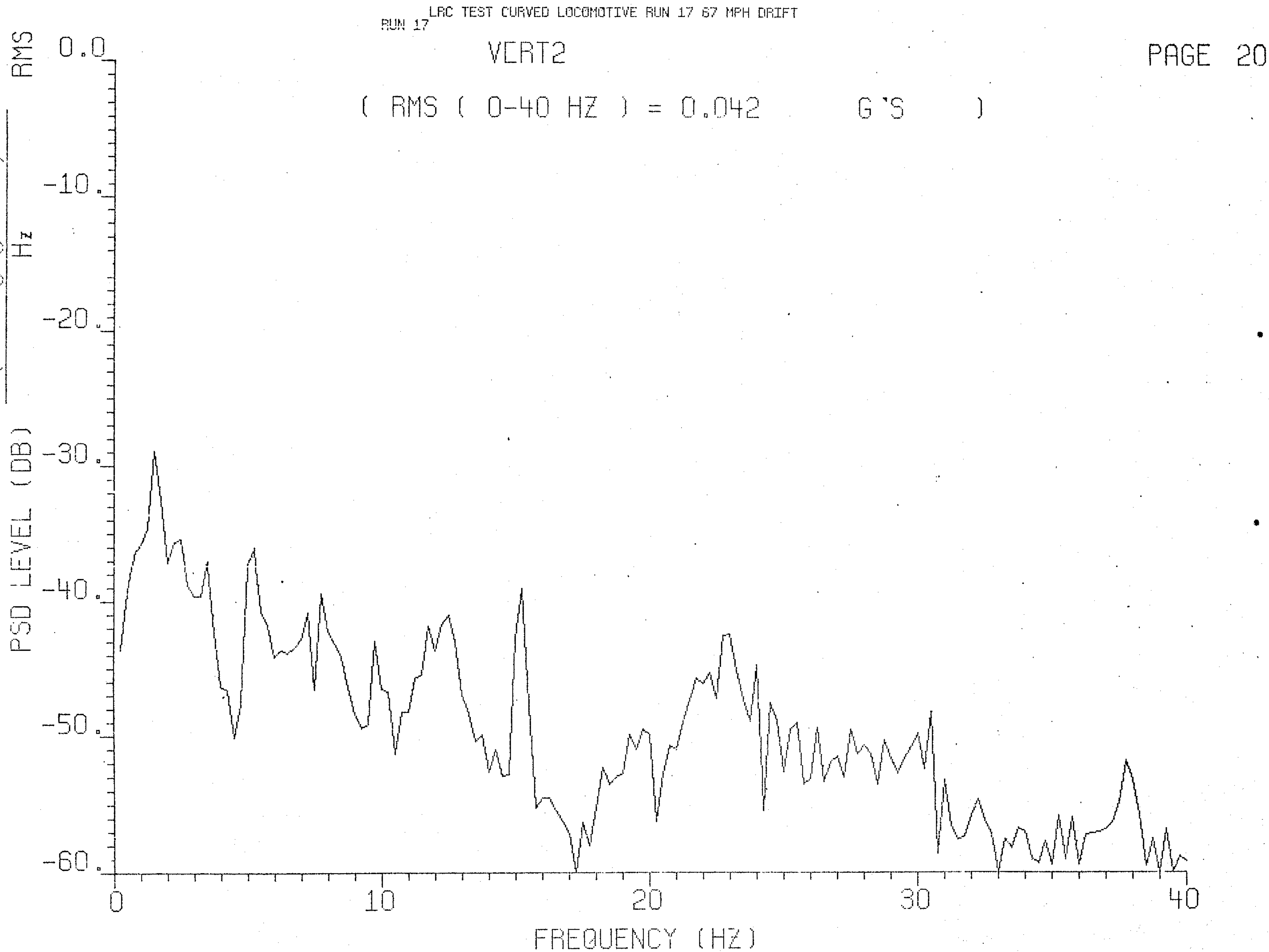
RUN 17 LRC TEST CURVED LOCOMOTIVE RUN 17 67 MPH DRIFT

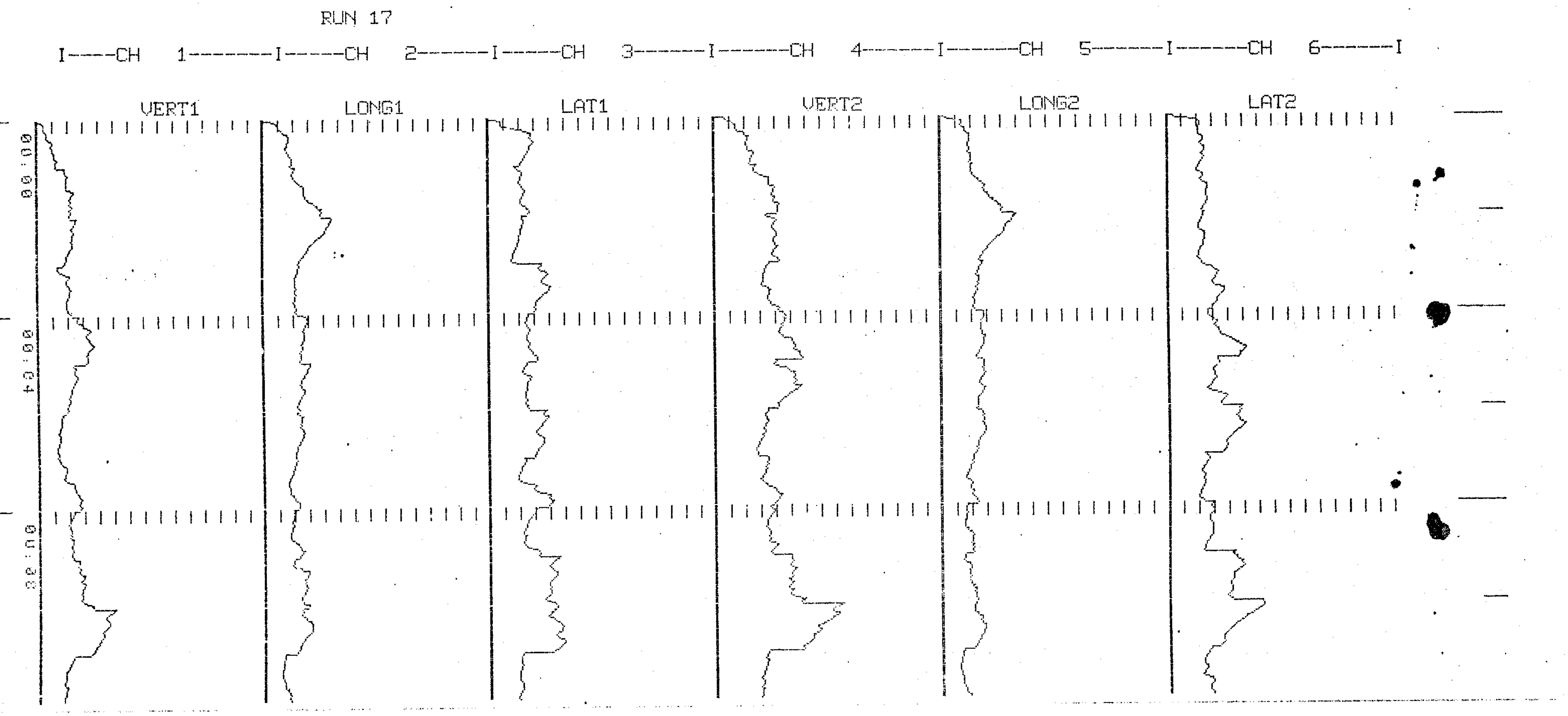
LAT2

PAGE 19

(RMS (0-40 HZ) = 0.038 G'S)




LRC TEST CURVED LOCOMOTIVE RUN 17 67 MPH DRIFT
RUN 17
VERT2
PAGE 20
(RMS (0-40 HZ) = 0.042 G'S)
PSD LEVEL (DB) (G'S / Hz)^2 RMS
0.0
-10.
-20.
-30.
-40.
-50.
-60.
0
10
20
30
40
FREQUENCY (HZ)



C H A N N E L   D E F I N I T I O N

CHANNEL NUMBER	DESCRIPTION				ENGINEERING UNITS PER COUNT	CHANNEL RANGE	UNITS PER MINOR DIVISION
1 - 1	VERT1	(G'S)	RMS	2 SECS/RECORD	0.0024420	1.50	0.100
2 = 2	LONG1	(G'S)	RMS	2 SECS/RECORD	0.0004884	0.15	0.010
3 - 3	LAT1	(G'S)	RMS	2 SECS/RECORD	0.0004884	0.15	0.010
4 = 4	VERT2	(G'S)	RMS	2 SECS/RECORD	0.0004884	0.15	0.010
5 - 5	LONG2	(G'S)	RMS	2 SECS/RECORD	0.0004884	0.15	0.010
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0.0004884	0.15	0.010