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Office of Research and Development Washington DC 20590

SAFETY MARGIN TESTING OF A 70-TON BOXCAR WITH SHIFTED PLYWOOD LADING

Test Results Data

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DOT/FRA/ORD-84/15.02

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03 - Rail Vehicles & Components

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PREFACE

A cooperative test effort between the Association of American Railroads (AAR) and the Federal Railroad Administration (FRA) was conducted at the Transportation Test Center (TTC), Pueblo, Colorado in the April-May-June period of 1982. The test vehicle used was the DOTX 503, which is a 50-foot 70-ton boxcar. The testing performed was primarily on the Vibration Test Unit (VTU) but also included longitudinal impacting and over-the-road measurements. The AAR test requirement, presented in Reference 1, and the FRA requirements, presented in Reference 2, were incorporated into the Implementation Plan, Reference 3.⁽¹⁾ The AAR objectives were primarily concerned with evaluation of the performance and operation of the VTU and to determine the feasibility of using the VTU as a rail vehicle simulator for damage prevention testing. Results of the AAR tests are contained in References 4 and 5.

The FRA objectives centered on the investigation of derailment cause and prevention using a boxcar and lading configuration that has been a suspected contributing cause to several derailments. The FRA tests were performed between June 8 and June 30, 1982; they have been identified as Safety Margin Testing and are the subject of this report.

MITRE involvement in these tests has been in support of both the AAR and FRA phases of testing. This report, however, covers only the Safety Margin Testing conducted at the Transportation Test Center's Rail Dynamics Laboratory (RDL).

A review of freight car derailment statistics has shown that the combination of curved track with out-of-specification low joints and boxcars with plywood lading has been frequently involved in derailments.⁽²⁾ It is suspected that in these cases the plywood lading had shifted laterally and was a major contributor to the cause of derailment.

The typical boxcar is 114 inches in inside width; thus there is a total lateral clearance of 18 inches with 4 x 8 plywood. AAR loading specifications require that the plywood be placed in

(1) The List of References can be found at the end of this report.

(2) Discussions with members of the Association of American Railroads (AAR) Subcommittee on Freight Claim and Damage Prevention; Tom Schoenleben, Chessie, Baltimore, Md., Harry Grosso, AAR, and Peter Kiliani, CONRAIL.

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the center (laterally) and that longitudinal wedging be effected with wooden spacers between each adjacent stack of plywood. Longitudinal preload is applied using air bags and held with wooden wedges. The objective of this AAR requirement is to minimize longitudinal dynamics and reduce the tendency for lateral shifting of the plywood.

The objectives of the Safety Margin Testing of this report are first to determine the threshold of track variations that will cause the plywood lading to shift and then to determine what track variations will result in wheel lift. The effect of various truck suspension systems, including hydraulic snubbers, on the response of the carbody and lading and the margin of derailment conditions were investigated.

This working paper is the second of a two volume report: Volume 1 was the basic report with summarized test data; Volume 2 contains the base test data and plots used in developing the final summary data and is in four sections. Section 1 contains carbody roll angle and vertical wheel load plots from the staggered rail tests ordered by run number. Sections 2, 3 and 4 contain Power Spectral Density (PSD) plots as summaries, as X and Z envelopes, and as comparisons of Configuration 1 and Configuration 2 responses.

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1. STAGGERED RAIL TEST RESULTS

Staggered rail tests were performed using rectified sine profile shapes. Each run was with constant cross level amplitudes of low joints and with decreasing frequencies corresponding to a speed slow down from 35 to 11 miles per hour. Successive runs were made with increased cross level for each new run until the lading started to shift or zero wheel load occurred. Table 1-1 presents a summary of the runs made identifying configuration, test, run number, and input level. Table 1-2 defines the changes made for each configuration.

The data presented are plots of carbody roll angle as a function of frequency (speed) and corresponding plots of vertical wheel load. The load data shown is from the left and right wheels of axle 1. However, in performance of the tests, all vertical wheel loads were monitored through the computer controlling the shaker. The shaker was stopped (limit checked) when any of the eight strain readings approached zero.

TABLE 1-1 TEST MATRIX

					SUPERELEV	ATED RAIL
					NORTH SI	
		EASED		ED RAIL	STAGGERE	
CONFIG.*	TRACK G		RUN/AM	PLITUDE	RUN/AMP	LITUDE
	RUN/ SCAL	E FACTOR		HES)	(INCH	
	CENTERED	SHIFTED	CENTERED	SHIFTED	CENTERED	SHIFTED
1	49/1.25	56/1/25	54/0.2	60/0.2		83/0.2
Ŧ	49/1.23 50/1.50	57/1.50	55/0.4			
			5570.4	61/0.4		84/0.3
	52/1.75#	58/1/75		62/0.6		85/0.4
	53/2.00#	59.2.00#				
2	122/1.25	118/1.25	126/0.2	98/0.2	128/0.2	101/0.2
	123/1.50	119/1.50	127/0.4	99/0.4	129/0.3	102/0.3
	124/1.75	120/1.75		100/0.6		103/0.4
	125/2.00#	121/2.00#		100/010		100,014
	· · · · · · · · · · · · · · · · · · ·			<u></u> .		
3				104/0.2		109/0.2
				106/0.4		108/0.3
		1 · · · · · · · · · ·		107/0.6	<u>-</u>	- · · · · · · · · · · · · · · · · · · ·
4				111/0 0		112/0 0
4				111/0.2		113/0.2
				110/0.4		112/0.3
5			•	115/0.3		117/0.2
				114/0.4		116/0.3
····						
6		130/1.25		132/0.2		135/0.2
		131/1.75		133/0.4		136/0.3
		_, -		134/0.6		137/0.4
· - · · · ·	······································			<u> </u>	<u></u>	
7		138/1.25		140/0.2		143/0.2
		139/1.75		141/0.4		144/0.3
				142/0.6		145/0.4
8		146/1.25		148/0.2		151/0.2
		147/1.75		149/0.4		152/0.3
<u></u>				150/0.6		

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*Suspension configurations are as shown in Table 1-2.

#These tests are invalid due to an error in the input track geometry introduced by the computerized process when increasing the amplitude.

Note: Total runs made from run #48 through run #153. Runs not listed were aborted or gave inconclusive results.

CONFIGURATION NUMBER	FRICTION(1) SNUBBERS	HYDRAULIC ⁽²⁾ SNUBBERS	SPRING RATES PER NEST(3) (1b./in.)
1	High	None	18,000
2	Low	Low	15,000
3	Low	High	15,000
4	High	Low	16,000
5	High	High	16,000
6	None	Low	13,000
7	None	High	13,000
8	Low	None	15,000

TABLE 1-2TRUCK CONFIGURATIONS, SAFETY MARGIN TESTING

(1) Friction snubber condition:

High = with inner and outer side springs
 (force equal about 5,000 lb./spring nest)
Low = with outer side spring only
 (force equal about 2,800 lb./spring nest)

(2)_{Hydraulic snubbers.} See Figure 3-4 for force rates.

(3)Spring rates per spring nest based on the following values: D5 outers: 2,140 lb./in. each

B-432 Side outers: 984 lb./in. each B-433 Side inners: 439 lb./in. each

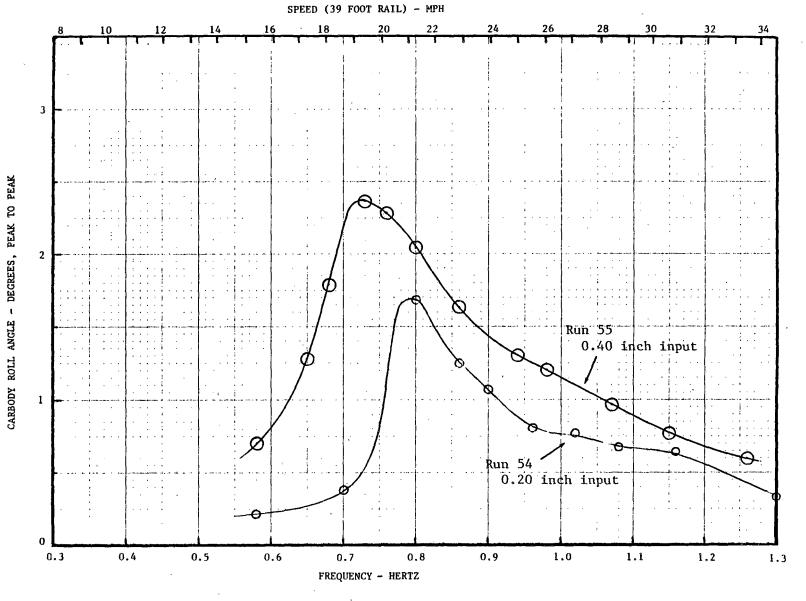
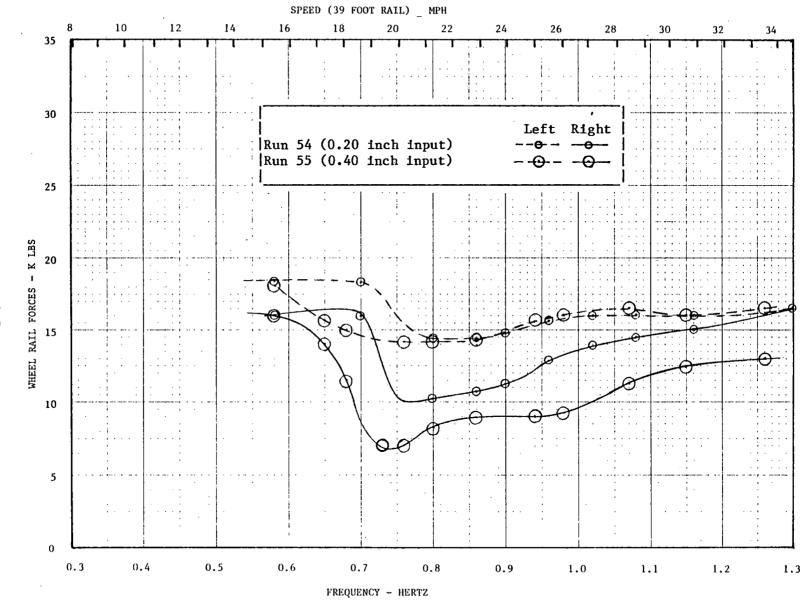


FIGURE 1-1 CARBODY ROLL ANGLES, CONFIGURATION 1, CENTERED LADING, STAGGERED RAIL TEST, RUNS 54 AND 55

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FIGURE 1-2 MINIMUM WHEEL VERTICAL LOAD, CONFIGURATION 1, CENTERED LADING, STAGGERED RAIL TEST RUNS 54 AND 55

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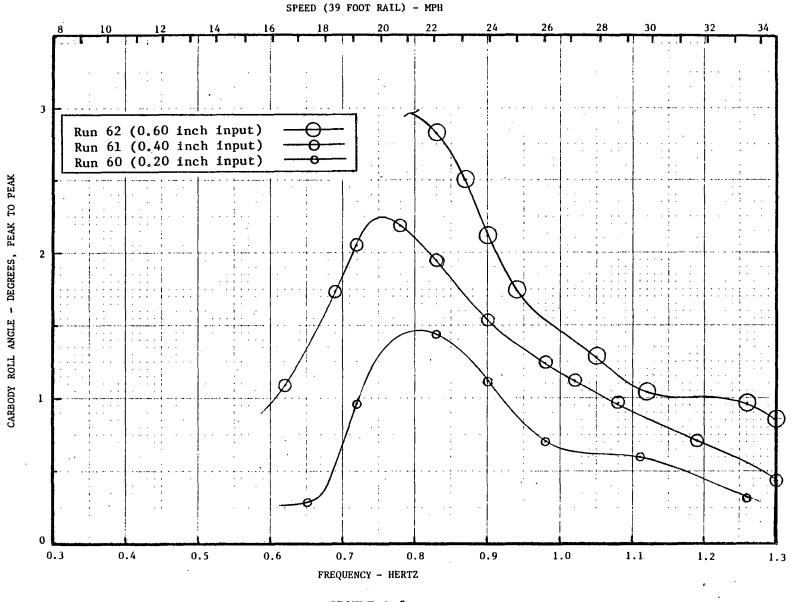


FIGURE 1-3 CARBODY ROLL ANGLES, CONFIGURATION 1, SHIFTED LADING, STAGGERED RAIL TEST, RUNS 60, 61, and 62

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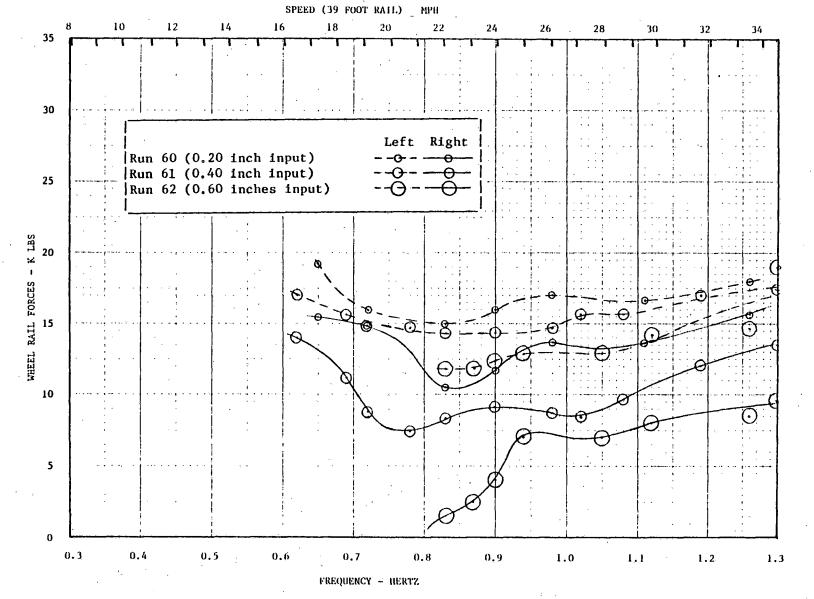


FIGURE 1-4 MINIMUM VERTICAL WHEEL LOAD, CONFIGURATION 1, LADING SHIFTED, STAGGERED RAIL TEST, RUNS 60, 61, and 62

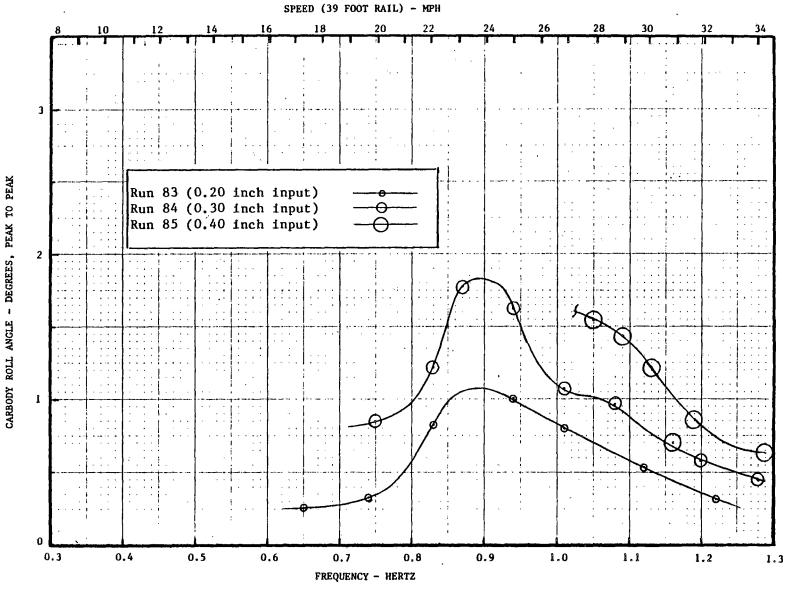


FIGURE 1-5 CARBODY ROLL ANGLES, CONFIGURATION 1, LADING SHIFTED, STAGGERED RAIL TEST WITH 3.0 INCH SUPERELEVATION, RUNS 83, 84, AND 85

1

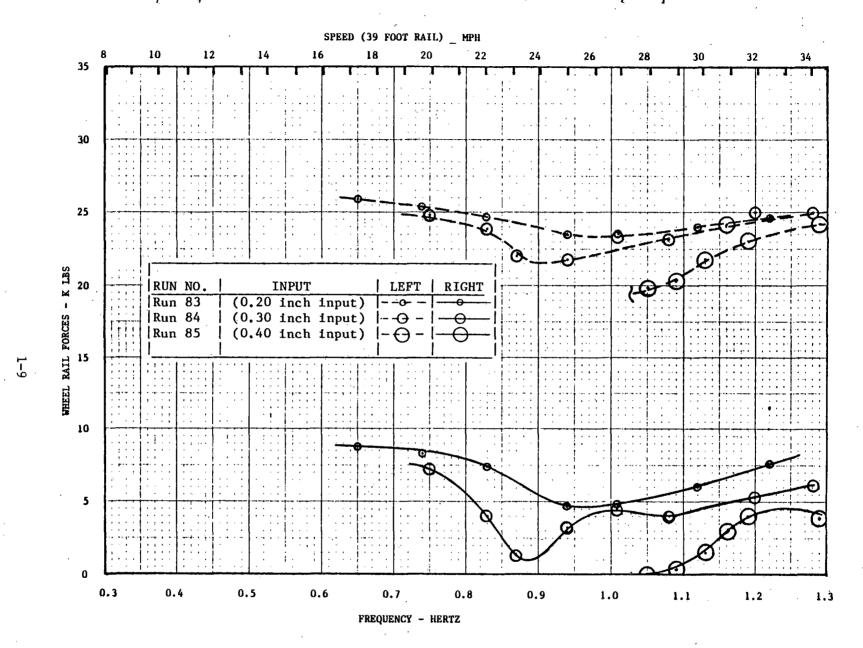


FIGURE 1-6 MINIMUM VERTICAL WHEEL LOAD, CONFIGURATION 1, LADING SHIFTED, STAGGERED RAIL TEST WITH 3.0 INCH SUPERELEVATION, RUNS 83, 84, and 85

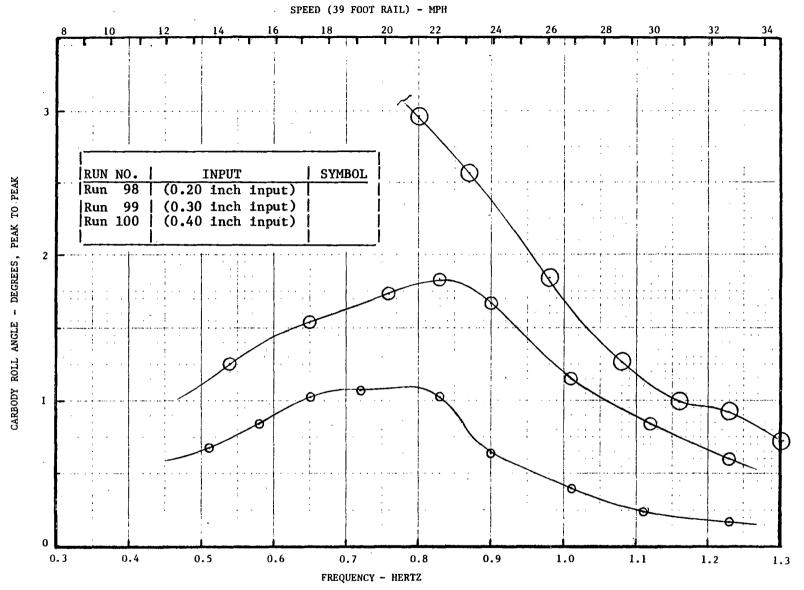
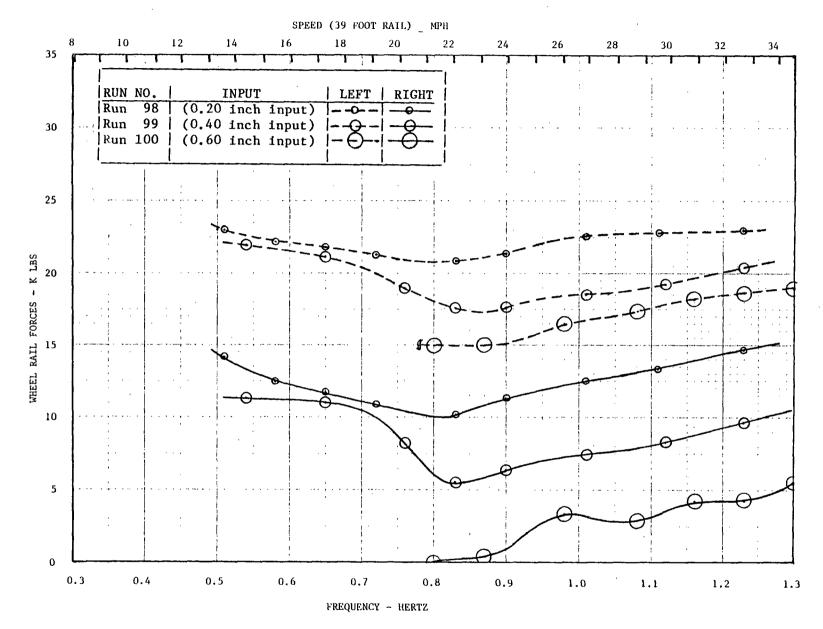


FIGURE 1-7 CARBODY ROLL ANGLE, CONFIGURATION 2, LADING SHIFTED, STAGGERED RAIL TEST, RUNS 98, 99, and 100

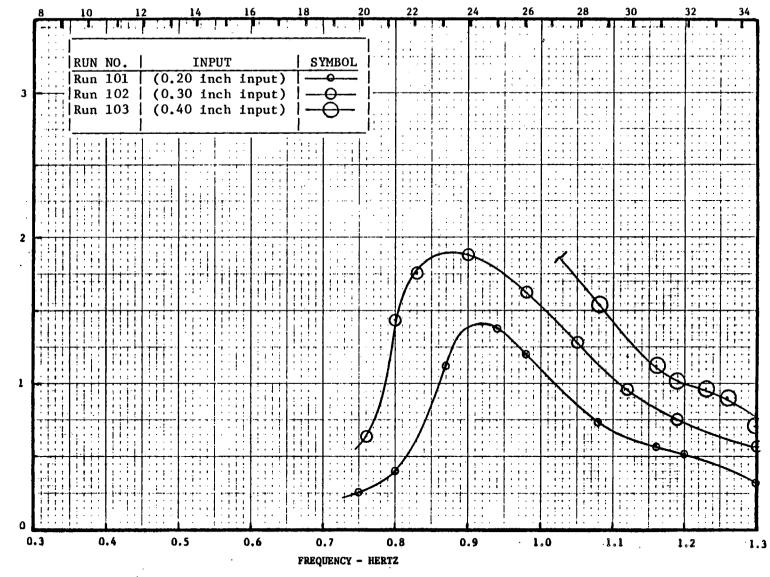


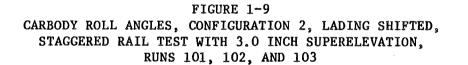
, *****

FIGURE 1-8 MINIMUM VERTICAL WHEEL LOADS, CONFIGURATION 2, LADING SHIFTED, STAGGERED RAIL TEST, RUNS 98, 99, and 100

CARBODY ROLL ANGLE - DEGREES, PEAK

TO PEAK





SPEED (39 FOOT RAIL) - MPH

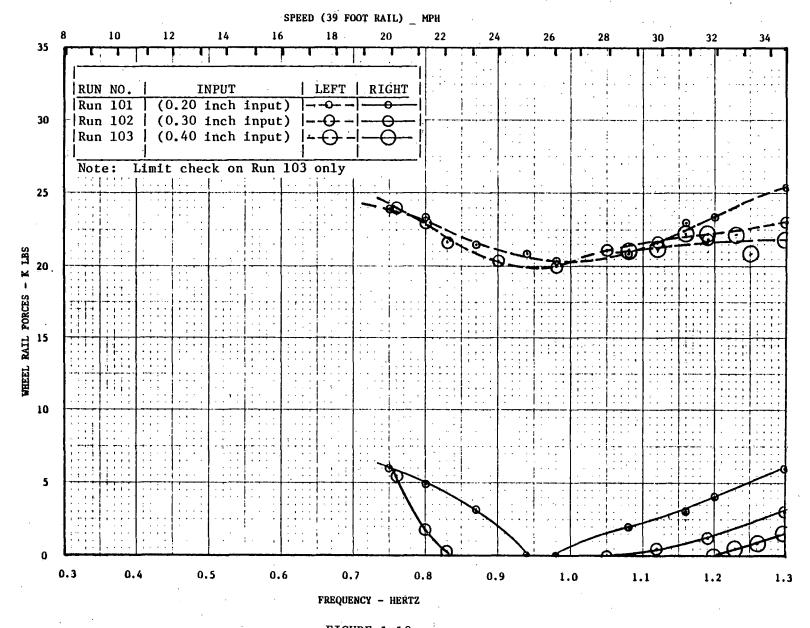


FIGURE 1-10 MINIMUM VERTICAL WHEEL LOAD, CONFIGURATION 2, LADING SHIFTED, STAGGERED RAIL TEST WITH 3.0 INCH SUPERELEVATION, RUNS 101, 102, AND 103

SPEED (39 FOOT RAIL) - MPH 16 18 20 22 28 24 26 30 8 10 12 14 32 34 INPUT RUN NO. SYMBOL Run 104 (0.20 inch input) -0-Run 106 (0.40 inch input) 3 (0.60 inch input) Run 107 Run 107 (0.60 inch) - DEGREES, PEAK TO PEAK Run 106 (0.40 inch) 2 0 CARBODY ROLL ANGLE 3 Run 104 (0.20 inch) ቡ 0 0.3 0.4 0.5 0.6 0.7 0.9 1.0 1.1 1.2 0.8 1.3 FREQUENCY - HERTZ

FIGURE 1-11 CARBODY ROLL ANGLES, CONFIGURATION 3, LADING SHIFTED, STAGGERED RAIL TESTS, RUNS 104, 106, and 107

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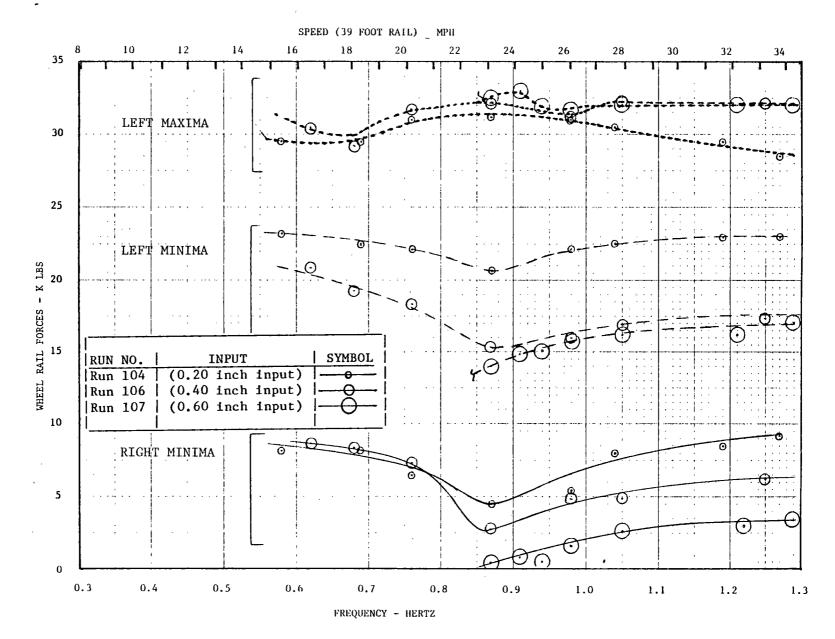
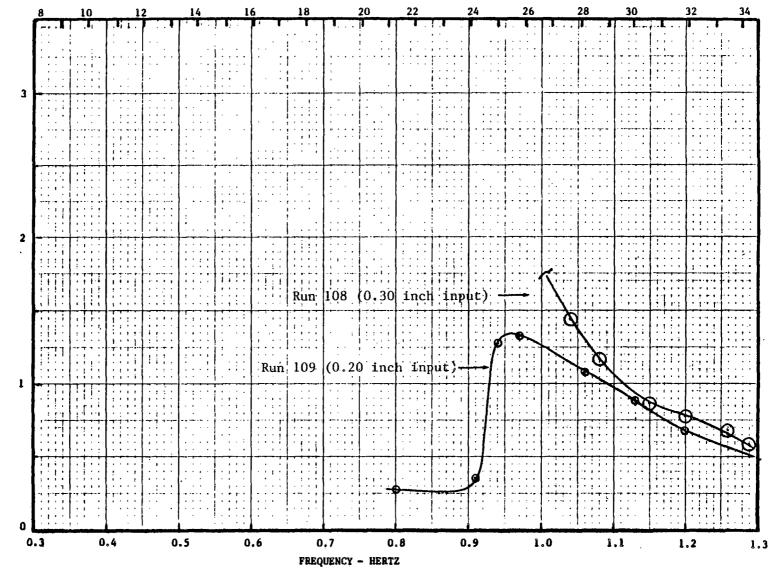
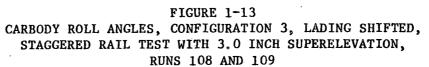


FIGURE 1-12 VERTICAL WHEEL LOADS, CONFIGURATION 3, LADING SHIFTED, STAGGERED RAIL TESTS, RUNS 104, 106, AND 107

1-15 . CARBODY ROLL ANGLE - DEGREES, PEAK TO PEAK



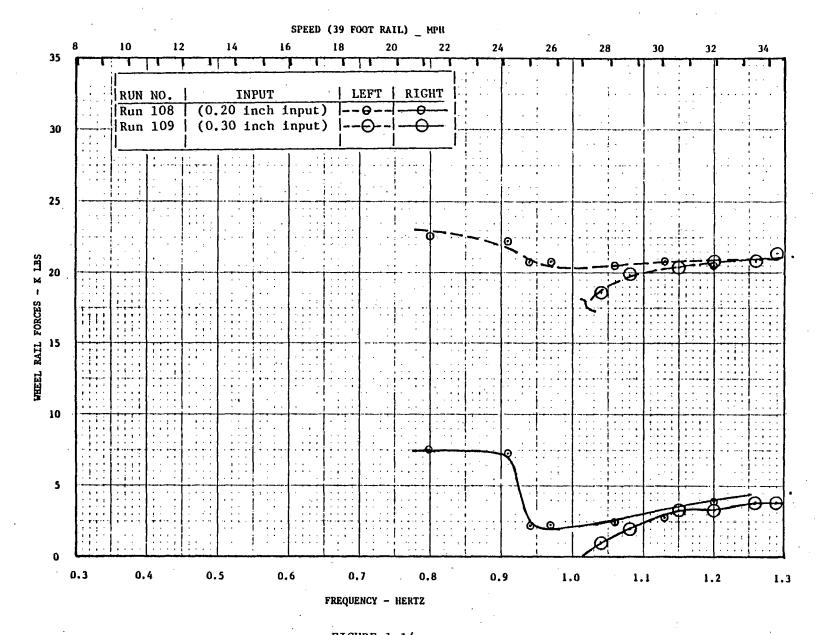


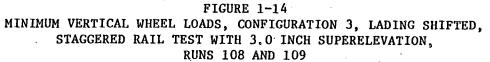
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SPEED (39 FOOT RAIL) - MPH

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CARBODY ROLL ANGLE - DEGREES, PEAK TO PEAK

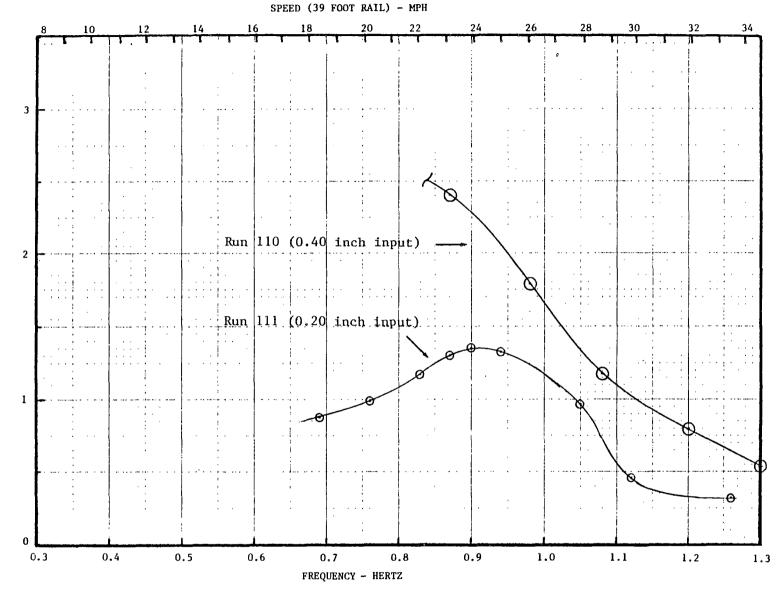


FIGURE 1-15 CARBODY ROLL ANGLES, CONFIGURATION 4, LADING SHIFTED, STAGGERED RAIL TESTS, RUNS 110 AND 111

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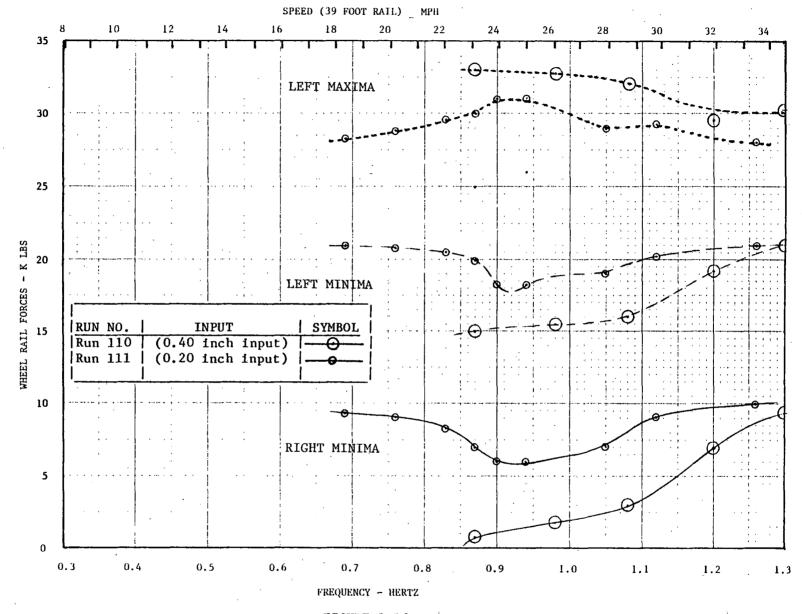


FIGURE 1-16 VERTICAL WHEEL LOADS, CONFIGURATION 4, LADING SHIFTED, STAGGERED RAIL TEST, RUNS 110 AND 111

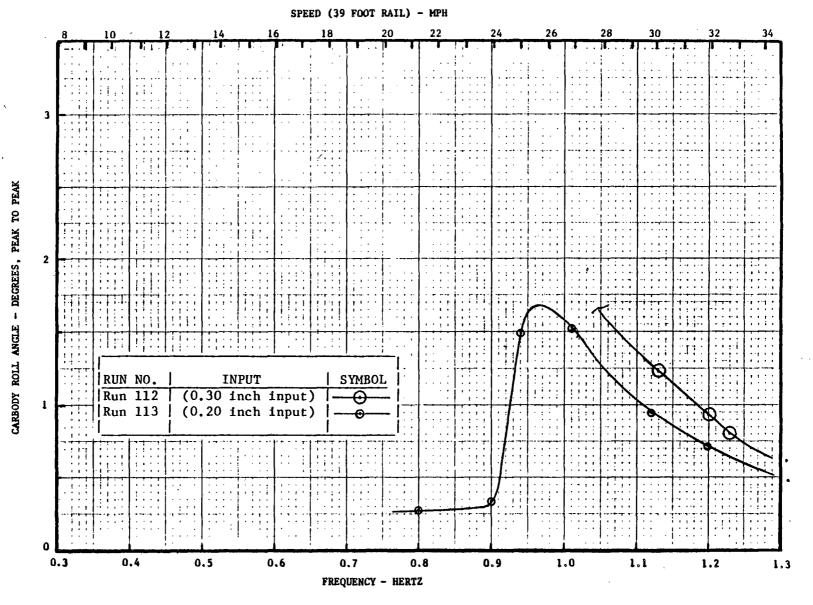
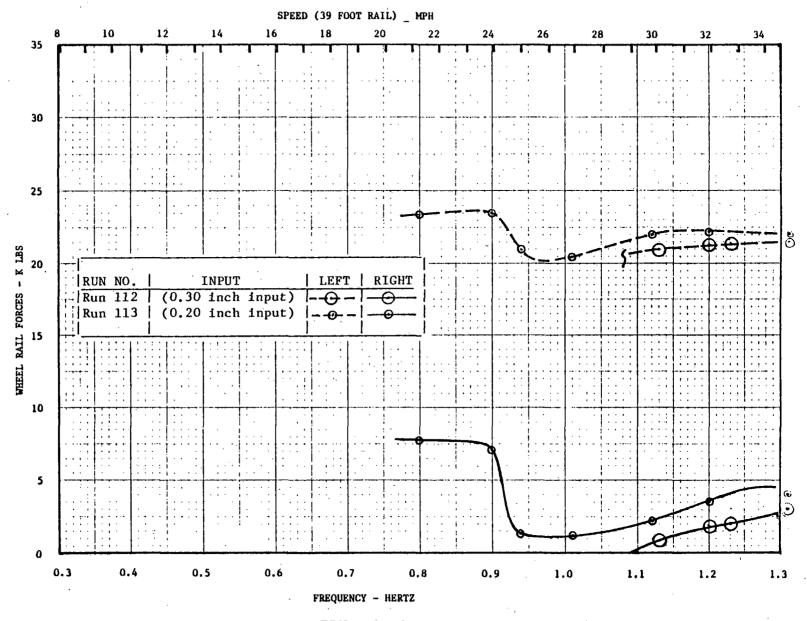
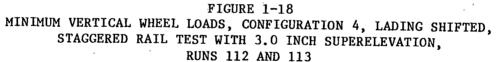


FIGURE 1-17 CARBODY ROLL ANGLES, CONFIGURATION 4, LADING SHIFTED, STAGGERED RAIL TEST WITH 3.0 INCH SUPERELEVATION, RUNS 112 AND 113





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DEGREES, PEAK TO 1 ANGLE CARBODY ROLL

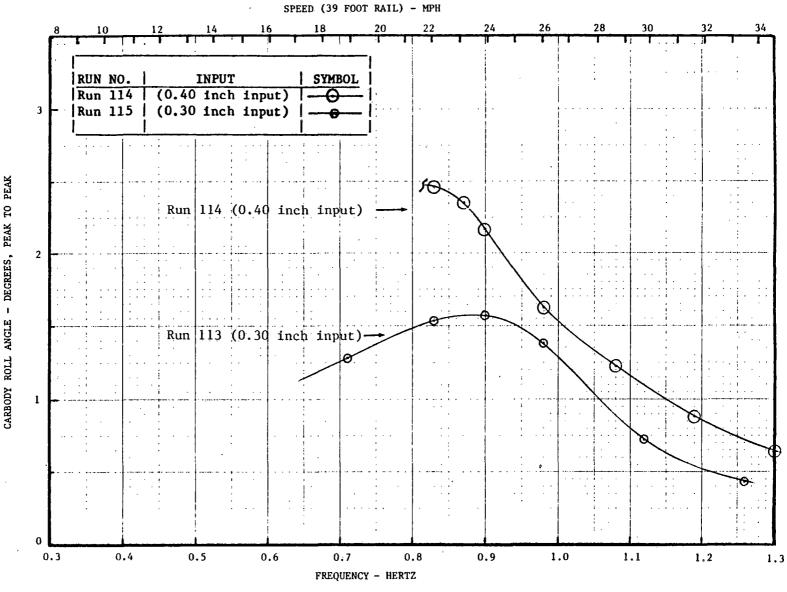
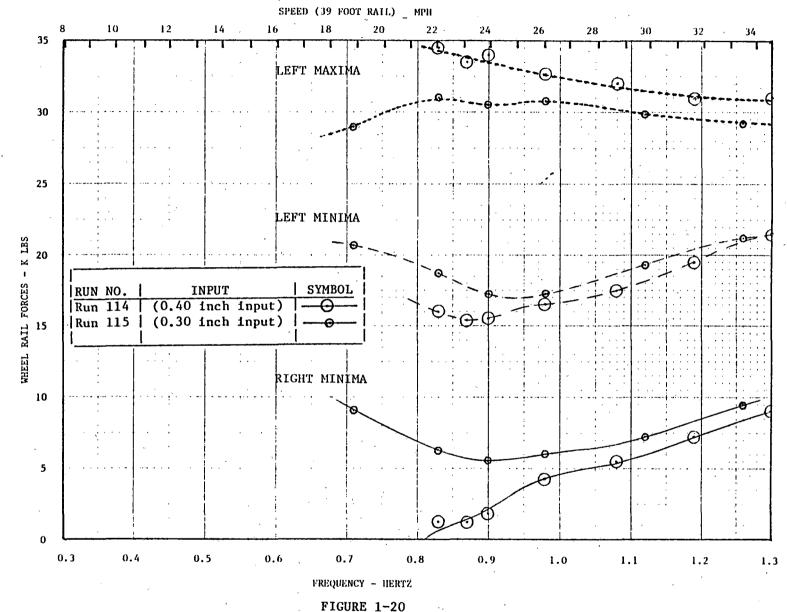


FIGURE 1-19 CARBODY ROLL ANGLES, CONFIGURATION 5, LADING SHIFTED, STAGGERED RAIL TESTS, RUNS 114 AND 115

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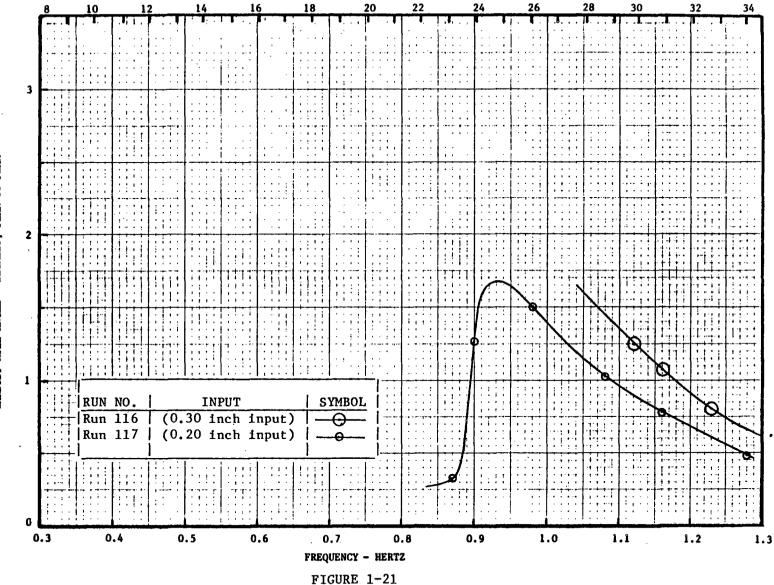
L-22



VERTICAL WHEEL LOADS, CONFIGURATION 5, LADING SHIFTED, STAGGERED RAIL TEST, RUNS 114 AND 115

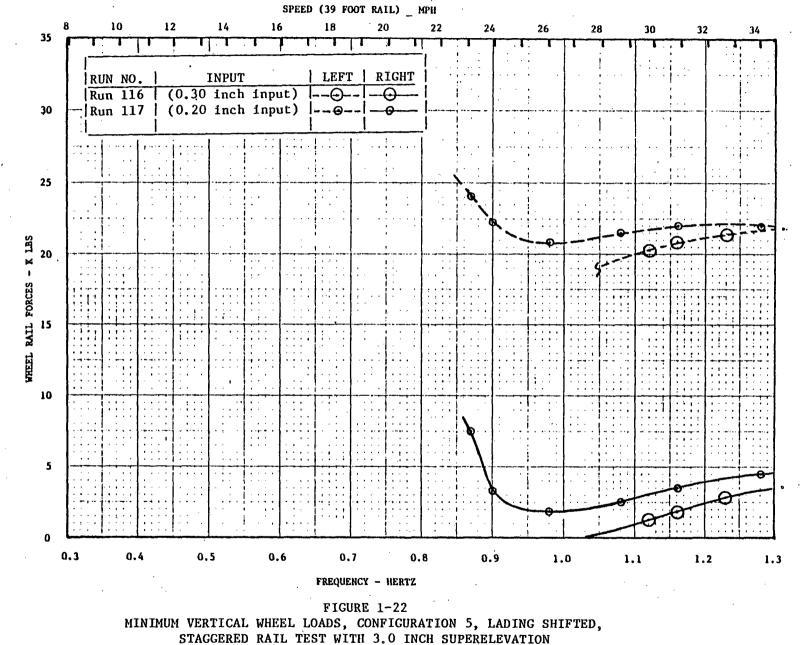
CARBODY ROLL ANGLE - DEGREES, PEAK TO PEAK

1-24



CARBODY ROLL ANGLES, CONFIGURATION 5, LADING SHIFTED, STAGGERED RAIL TEST WITH 3.0 INCH SUPERELEVATION RUNS 116 AND 117

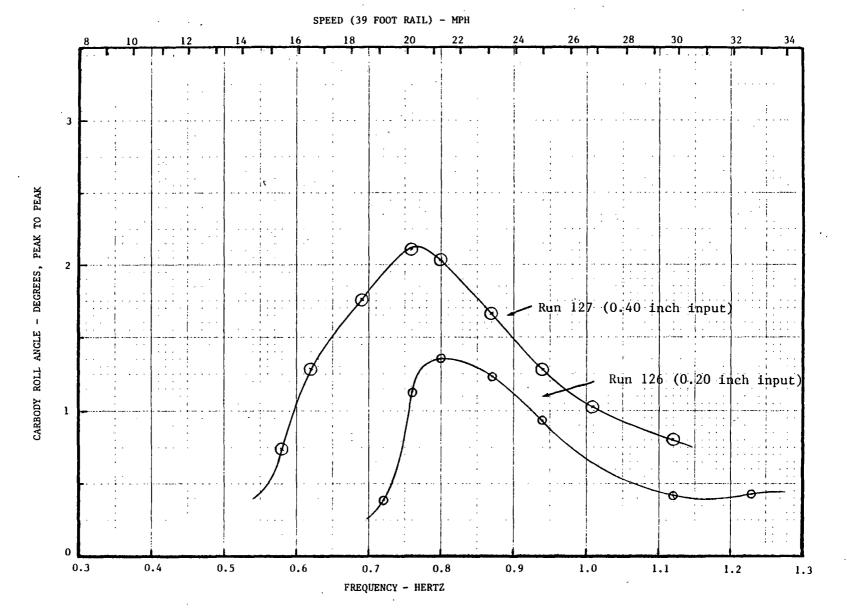
SPEED (39 FOOT RAIL) - MPH

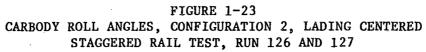


RUNS 116 AND 117

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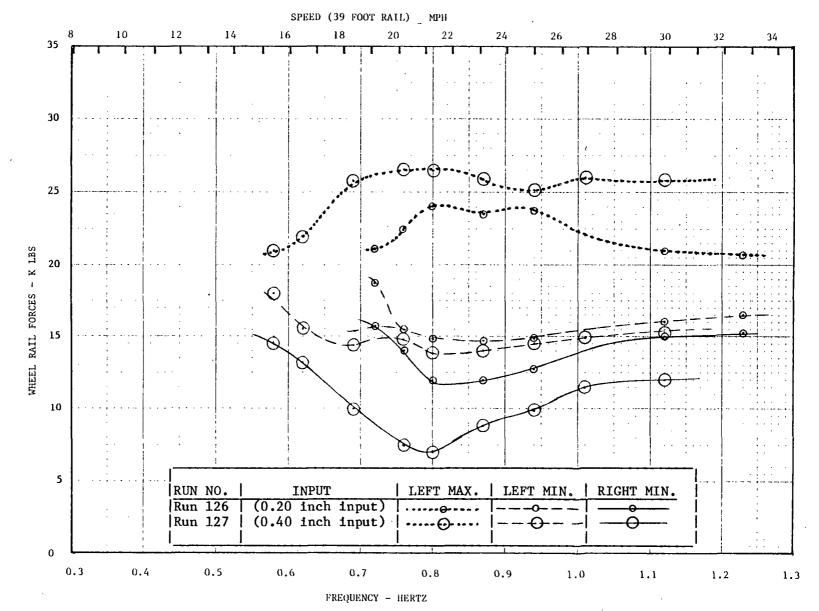
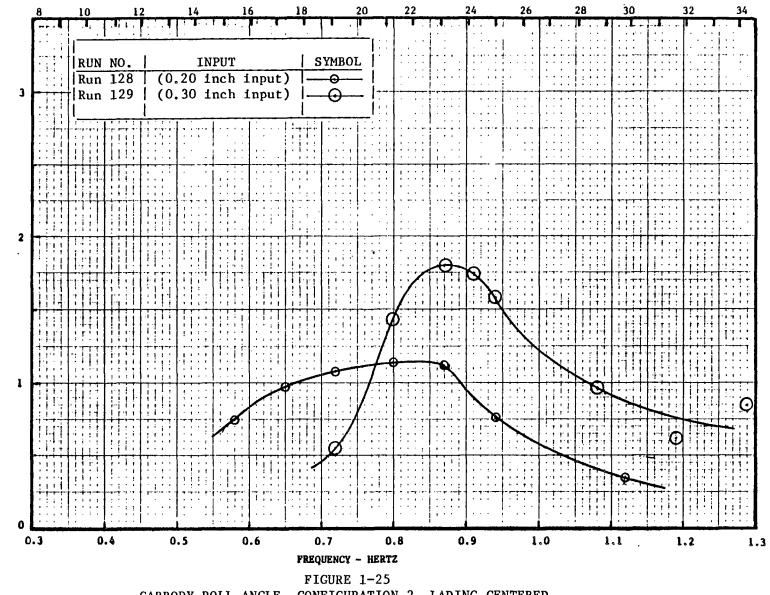
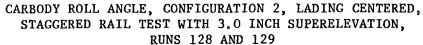


FIGURE 1-24 VERTICAL WHEEL LOAD, CONFIGURATION 2, LADING CENTERED, STAGGERED RAIL TEST, RUNS 126 AND 127



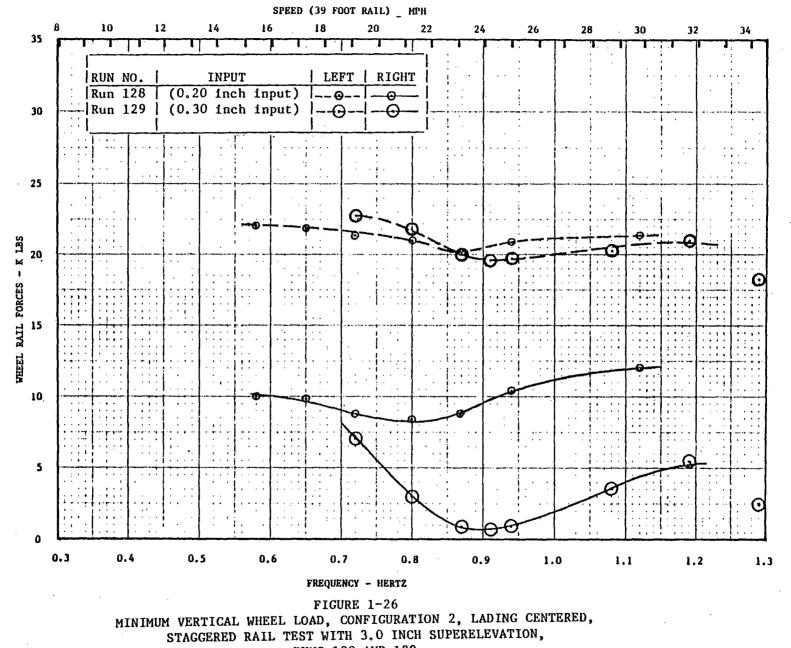


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CARBODY ROLL ANGLE - DEGREES, PEAK TO PEAK

1-28

SPEED (39 FOOT RAIL) - MPH .



RUNS 128 AND 129

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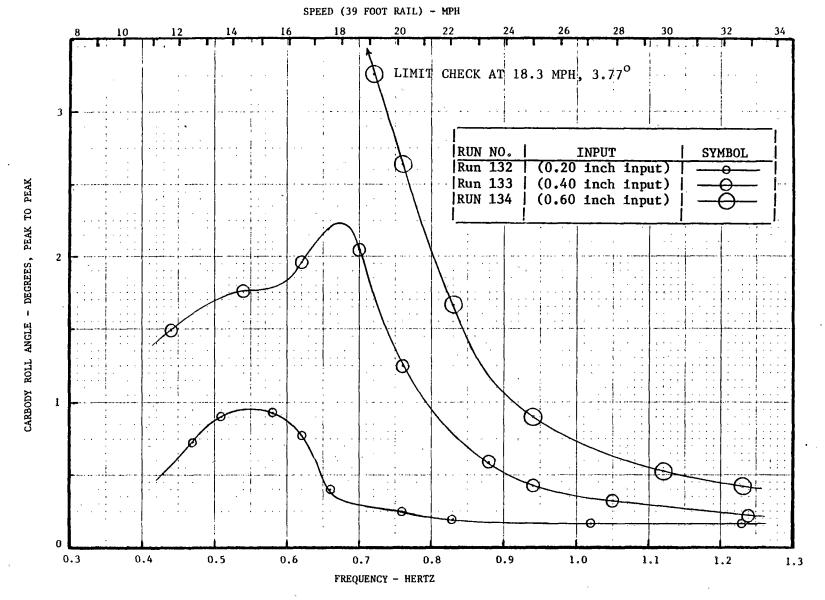
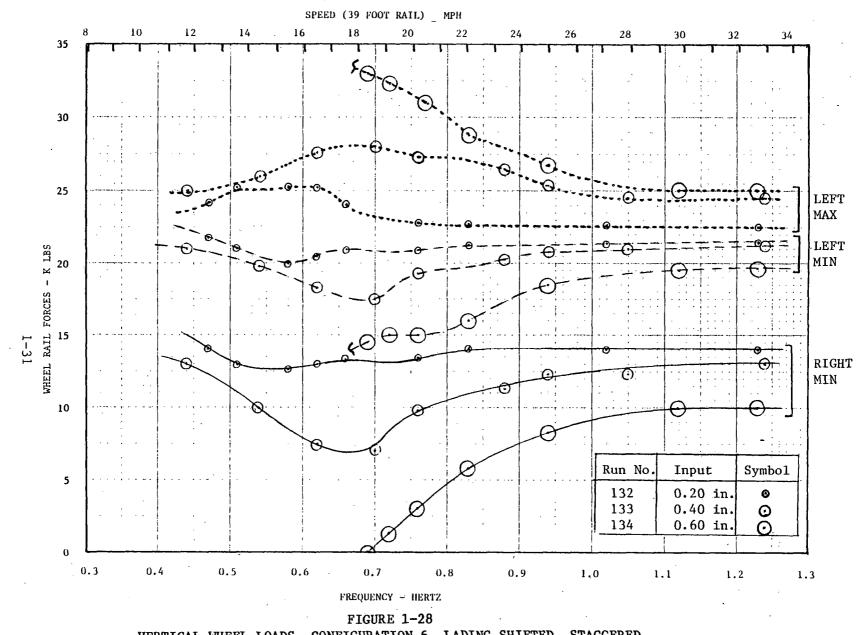


FIGURE 1-27 CARBODY ROLL ANGLE, CONFIGURATION 6, LANDING SHIFTED, STAGGERED RAIL TEST, RUNS 132, 133 AND 134

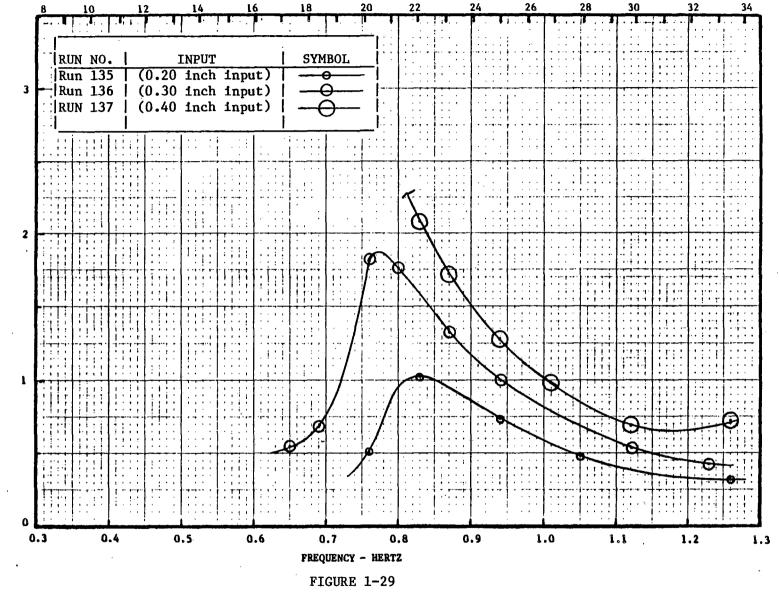
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VERTICAL WHEEL LOADS, CONFIGURATION 6, LADING SHIFTED, STAGGERED RAIL TEST, RUNS 132, 133, AND 134

CARBODY ROLL ANGLE - DEGREES, PEAK TO PEAK

1-32

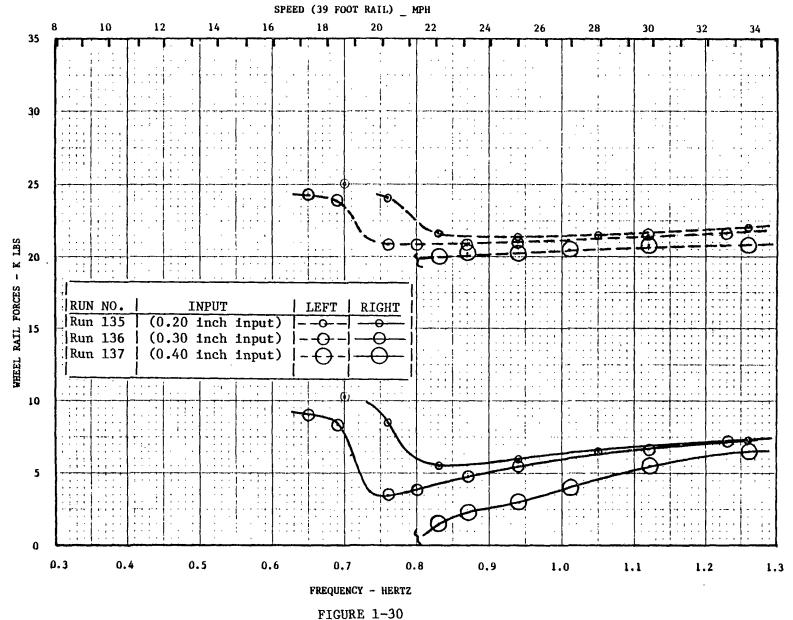


SPEED (39 FOOT RAIL) - MPH

CARBODY ROLL ANGLE, CONFIGURATION 6, LADING SHIFTED, STAGGERED RAIL TEST WITH 3.0 INCH SUPERELEVATION,

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RUNS 135, 136, AND 137



MINIMUM VERTICAL WHEEL LOADS, CONFIGURATION 6, STAGGERED RAIL TEST WITH 3.0 INCH SUPERELEVATION, RUNS 135, 136 AND 137

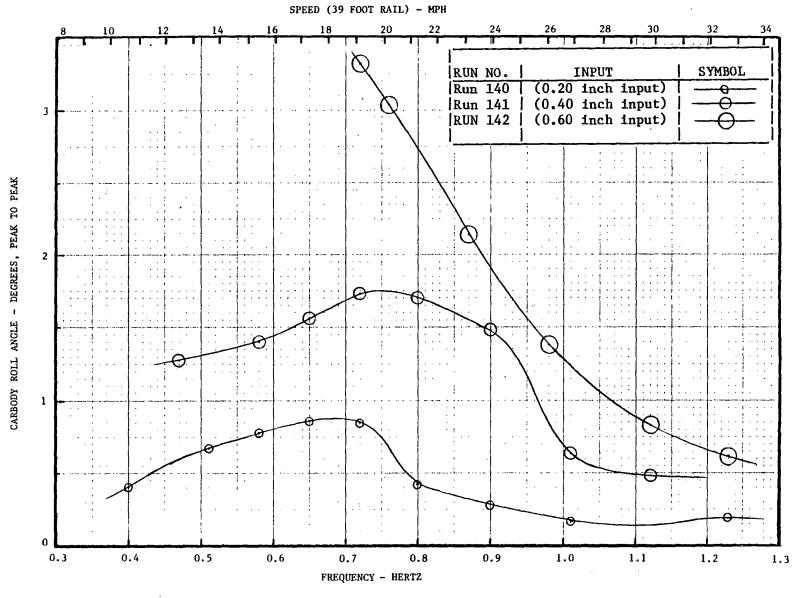
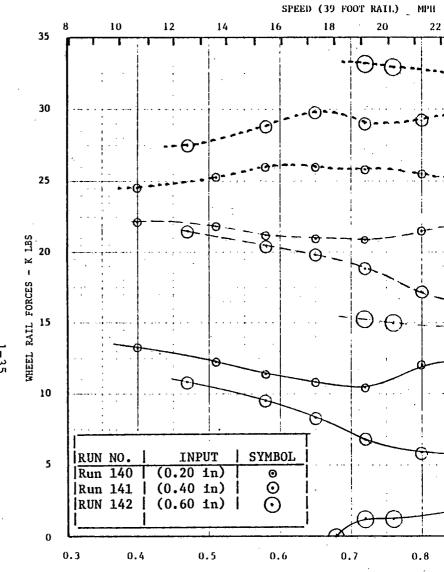


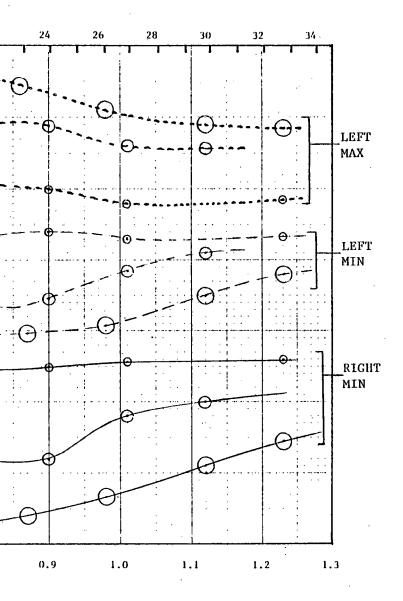
FIGURE 1-31 CARBODY ROLL ANGLE, CONFIGURATION 7, LADING SHIFTED, STAGGERED RAIL TEST, RUNS 140, 141, AND 142

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FREQUENCY - HERTZ

FIGURE 1-32 VERTICAL WHEEL LOAD, CONFIGURATION 7 STAGGERED RAIL TEST



LADING SHIFTED,

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22 18 20 24 28 30 10 12 14 16 26 32 34 RUN NO. INPUT SYMBOL (0.20 inch input) Run 143 -0---- |Run 144 (0.30 inch input) 3 RUN 145 (0.40 inch input) 2 LLL. 1 -0-0.5 0.6 0.7 0.9 1.0 1.1 0.3 0.4 0.8 1.2 1.3 FREQUENCY - HERTZ

SPEED (39 FOOT RAIL) - MPH

FIGURE 1-33 CARBODY ROLL ANGLE, CONFIGURATION 7, LADING SHIFTED, STAGGERED RAIL TEST WITH 3.0 INCH SUPERELEVATION

PEAK TO PEAK

DECREES,

1

CARBODY ROLL ANGLE

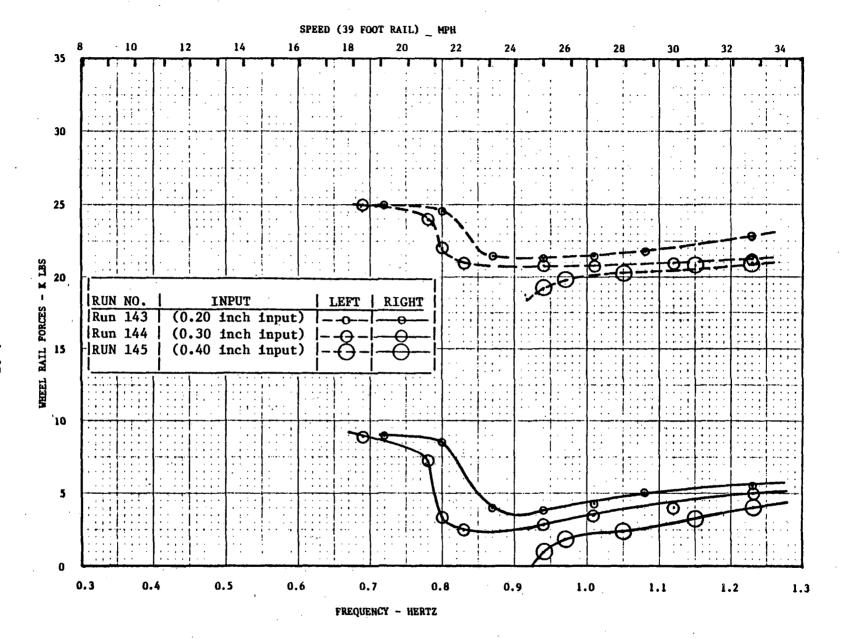


FIGURE 1-34 MINIMUM VERTICAL WHEEL LOADS, CONFIGURATION 7, LADING SHIFTED, STAGGERED RAIL TEST WITH 3.0 INCH SUPERELEVATION

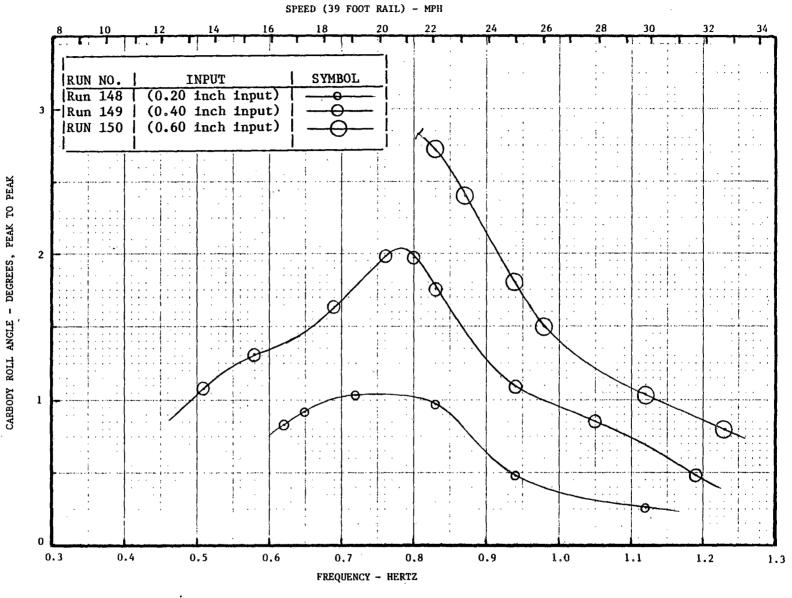


FIGURE 1-35 CARBODY ROLL ANGLE, CONFIGURATION 8, LADING SHIFTED, STAGGERED RAIL TEST

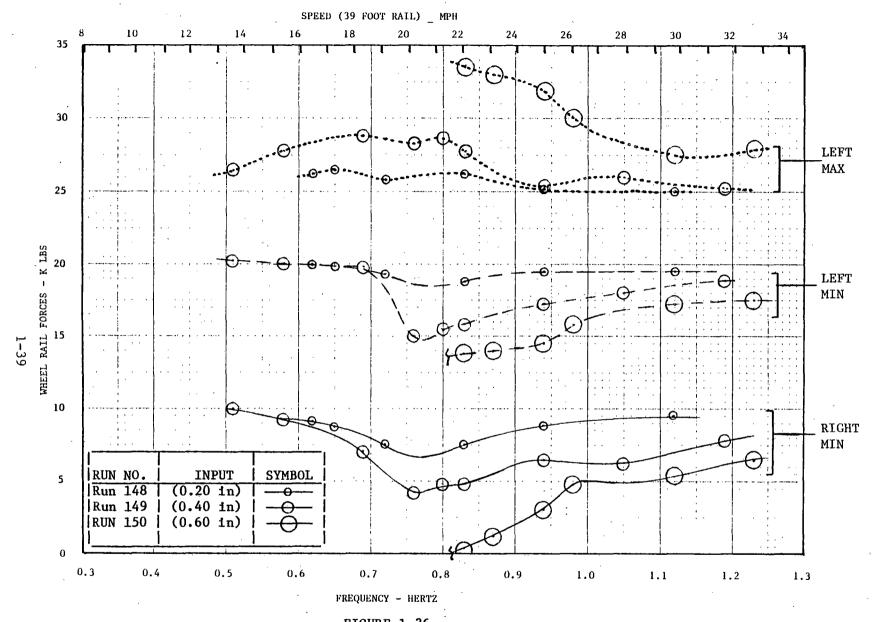


FIGURE 1-36 VERTICLE WHEEL LOADS, CONFIGURATION 8, LADING SHIFTED, STAGGERED RAIL TEST

22 20 24 26 28 30 32 16 18 10 12 14 34 , **, , , ,** RUN NO. INPUT SYMBOL Run 151 (0.20 inch input) O. 3 Run 152 (0.30 inch input) 2 1 i 0.4 0.5 0.6 0.7 0.8 0.9 1.0 1.1 0.3 1.2 1.3 FREQUENCY - HERTZ

> FIGURE 1-37 CARBODY ROLL ANGLES, CONFIGURATION 8, LADING SHIFTED, STAGGERED RAIL TEST WITH 3.0 INCH SUPERELEVATION

CARBODY ROLL ANGLE - DEGREES, PEAK TO PEAK

1-40

SPEED (39 FOOT RAIL) - MPH

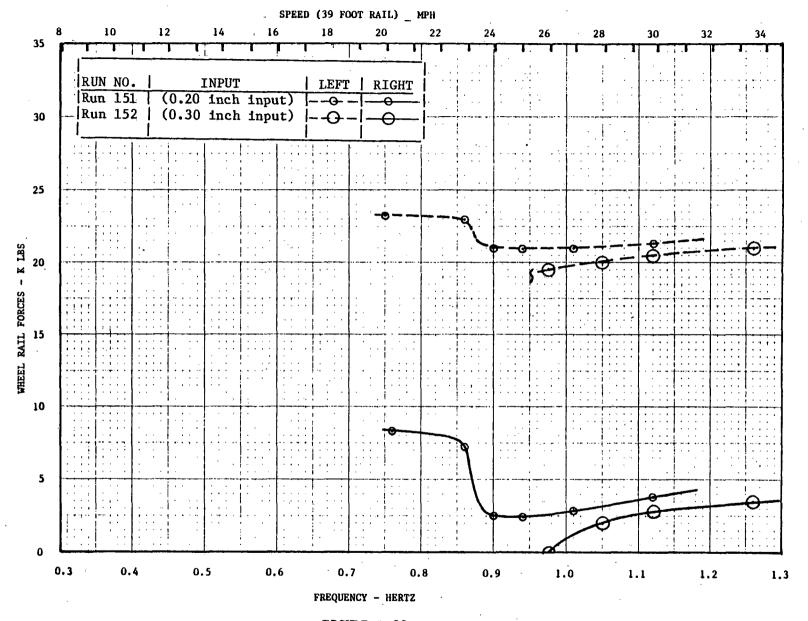


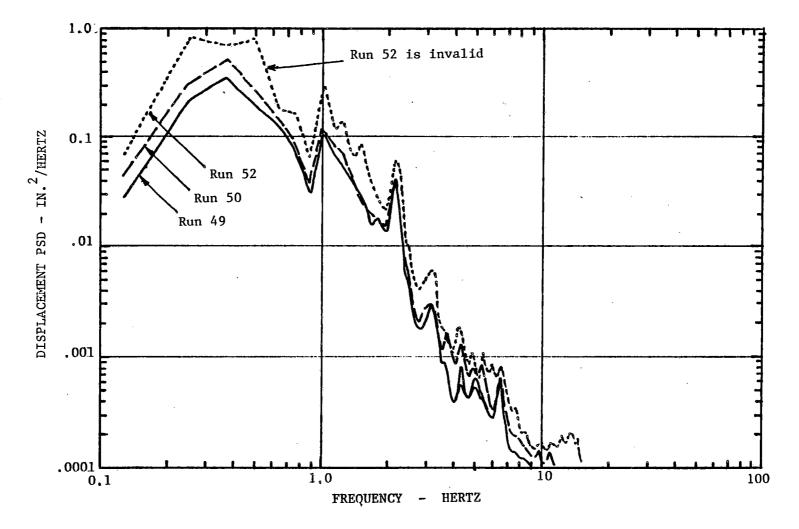
FIGURE 1-38 MINIMUM VERTICAL WHEEL LOAD, CONFIGURATION 8, LADING SHIFTED, STAGGERED RAIL TEST WITH 3.0 INCH SUPERELEVATION

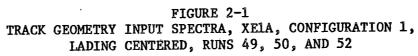
1-4]

2. SUMMARY POWER SPECTRAL DENSITY PLOTS FROM TRACK GEOMETRY TESTS

This section contains summary plots of input displacements and response accelerations from the Track Geometry (TG) tests. The data is all in PSD spectra from measurements over the same 80 second sections of the TG test. The data is for the following measurements:

- XEIA Piston Displacement Actuator 1A, vertical, inches.
- XE1C Piston Displacement Actuator 1C, lateral, inches.
- A8Z Vertical acceleration of lading on top right side, A end of car, g's.
- A9X Lateral acceleration of lading on top right side, A end of car, g's.
- A14Z Vertical acceleration of carbody on bottom right side, A end of car, g's.
- A15X Lateral acceleration of carbody on bottom right side, A end of car, g's.
- A17X Lateral acceleration of carbody on top right side, B end of car, g's.





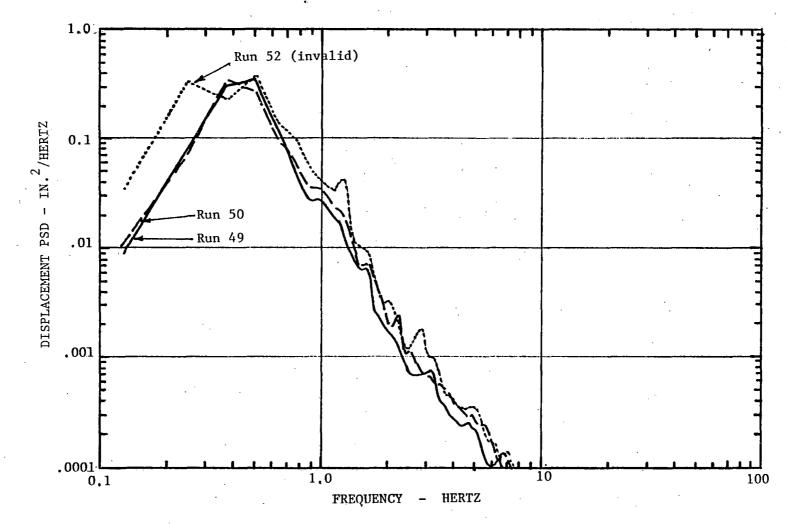


FIGURE 2-2 TRACK GEOMETRY INPUT SPECTRA, XE1C, CONFIGURATION 1, LADING CENTERED, RUNS 49, 50, AND 52

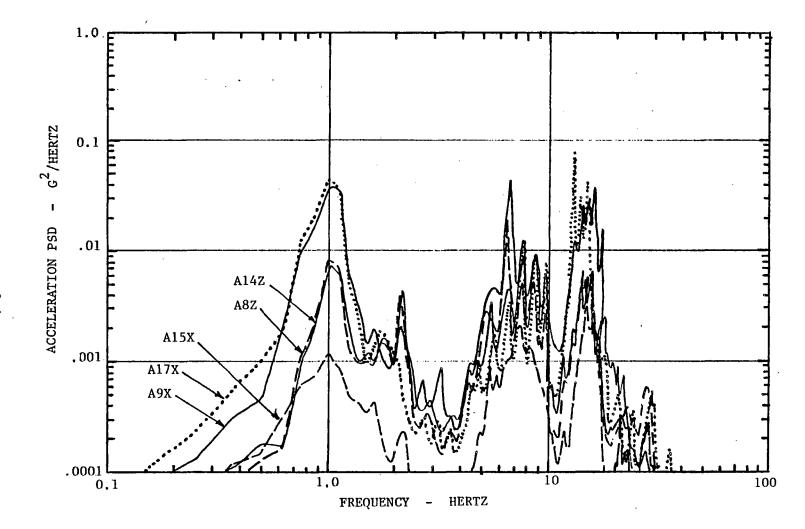


FIGURE 2-3 TRACK GEOMETRY RESPONSE SPECTRA, CONFIGURATION 1, LADING CENTERED, RUN 49, 1.25 LEVEL

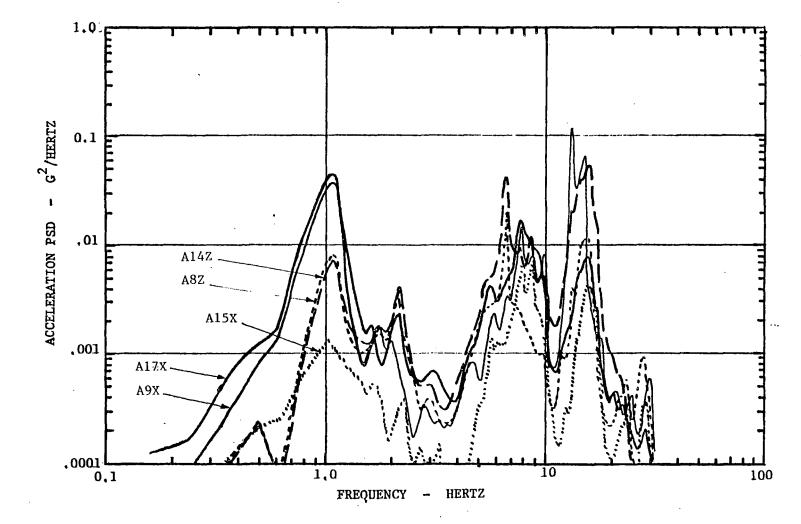


FIGURE 2-4 TRACK GEOMETRY RESPONSE SPECTRA, CONFIGURATION 1, LADING CENTERED, RUN 50, 1.50 LEVEL

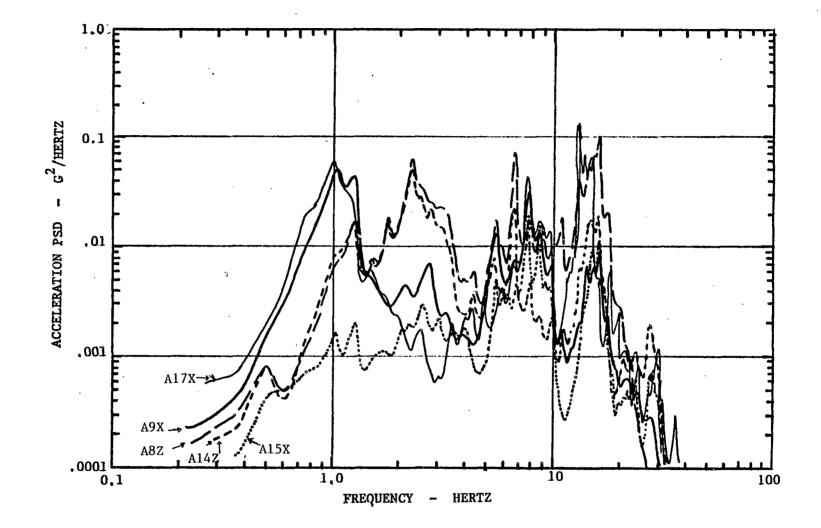


FIGURE 2-5 TRACK GEOMETRY RESPONSE SPECTRA, CONFIGURATION 1, LADING CENTERED, RUN 52, 1.75 LEVEL

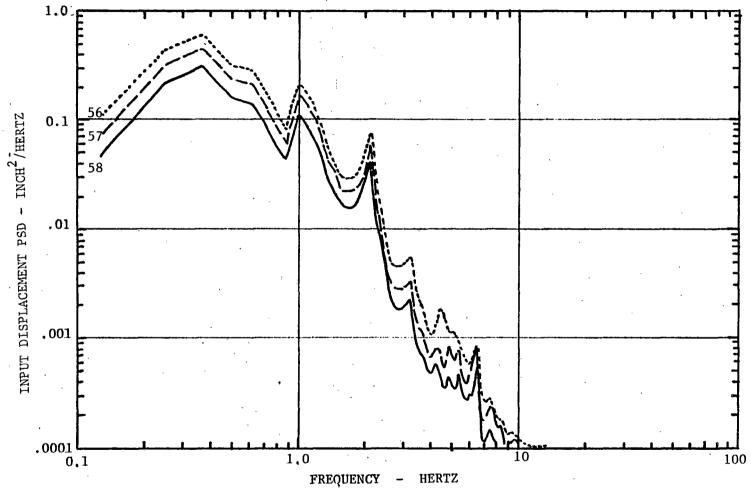
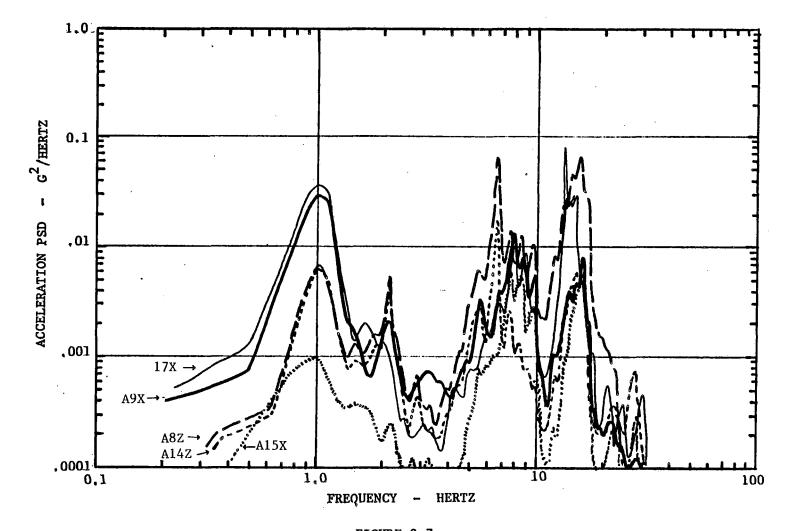
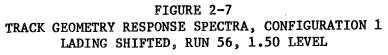
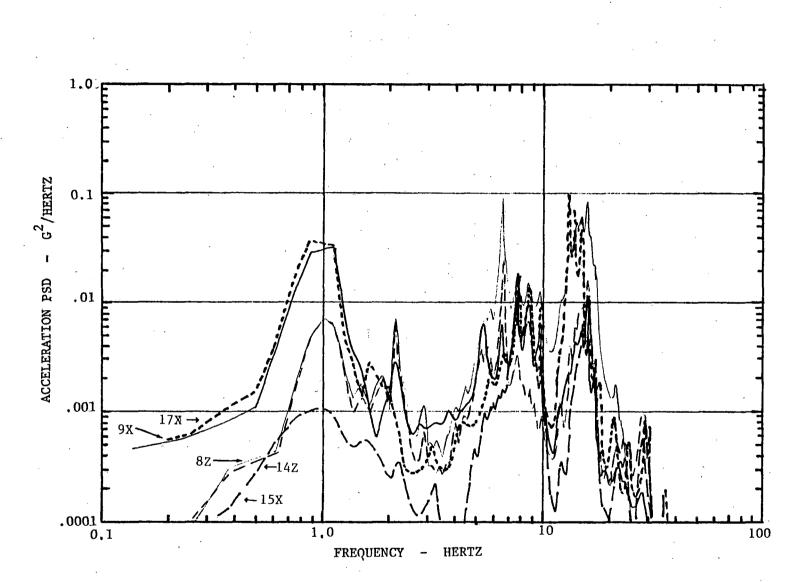
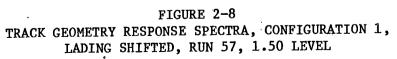


FIGURE 2-6 TRACK GEOMETRY INPUT SPECTRA, XE1A, CONFIGURATION 1, LADING SHIFTED, RUNS 56, 57, AND 58









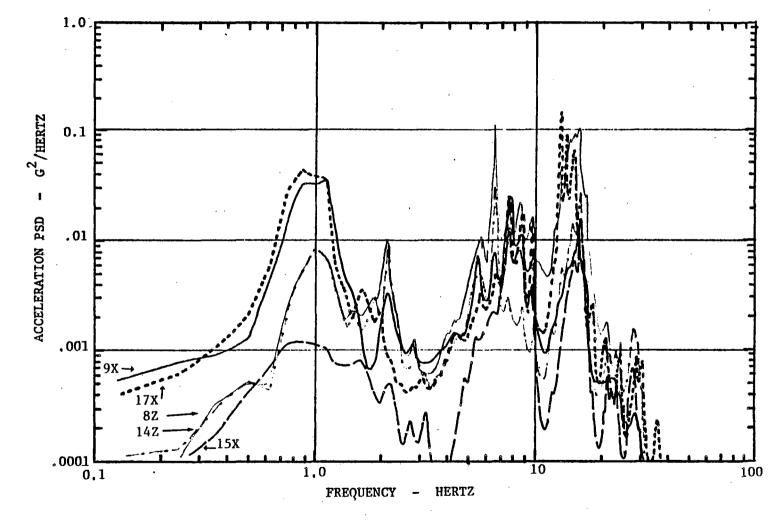
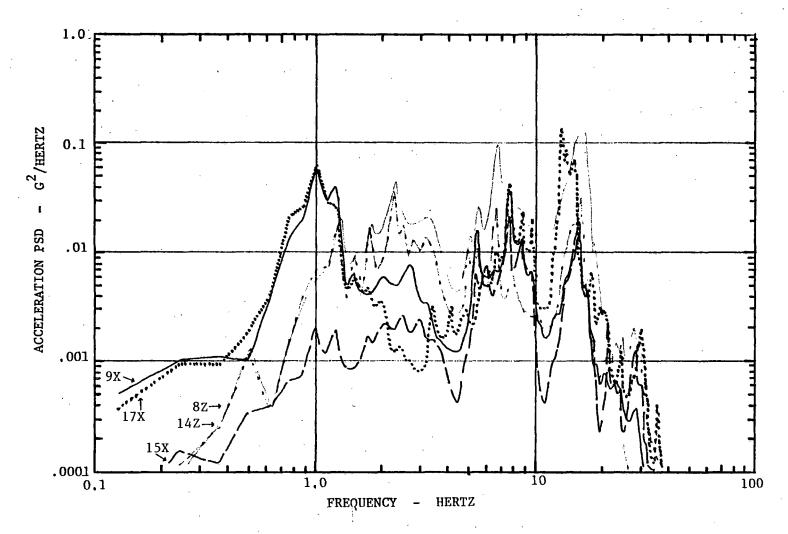
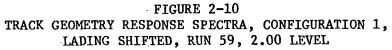
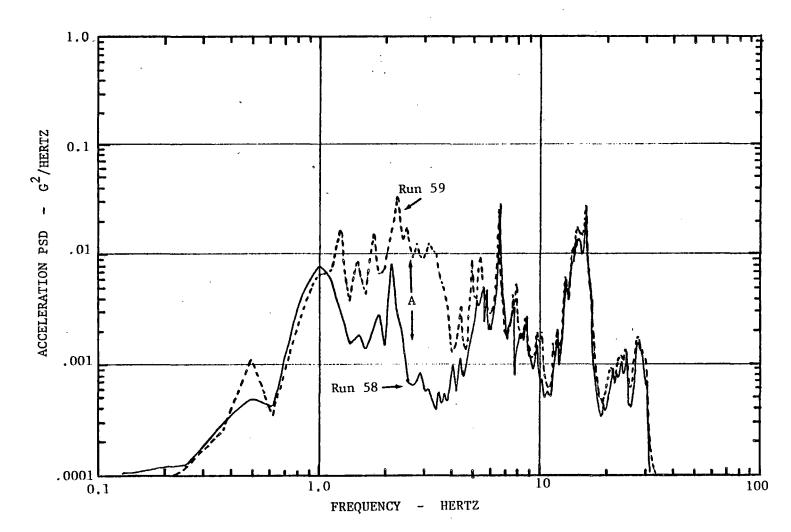
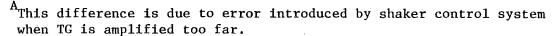


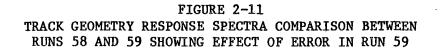
FIGURE 2-9 TRACK GEOMETRY RESPONSE SPECTRA, CONFIGURATION 1, LADING SHIFTED, RUN 58, 1.75 LEVEL



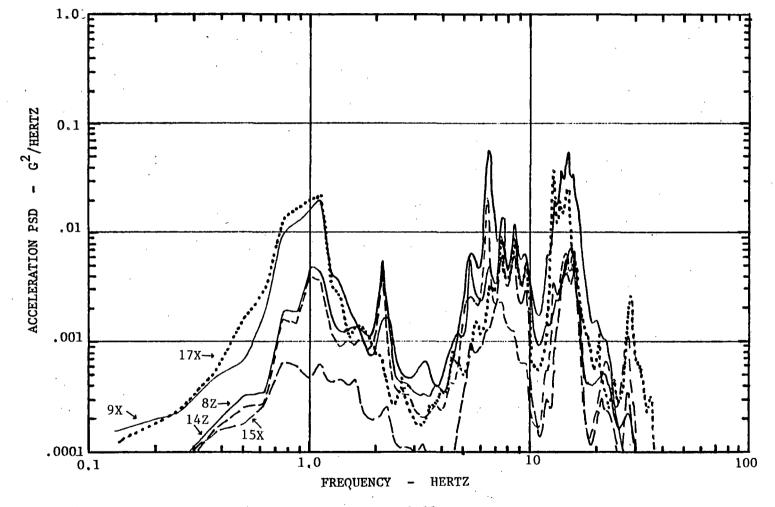


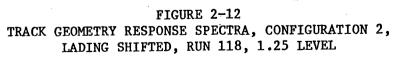


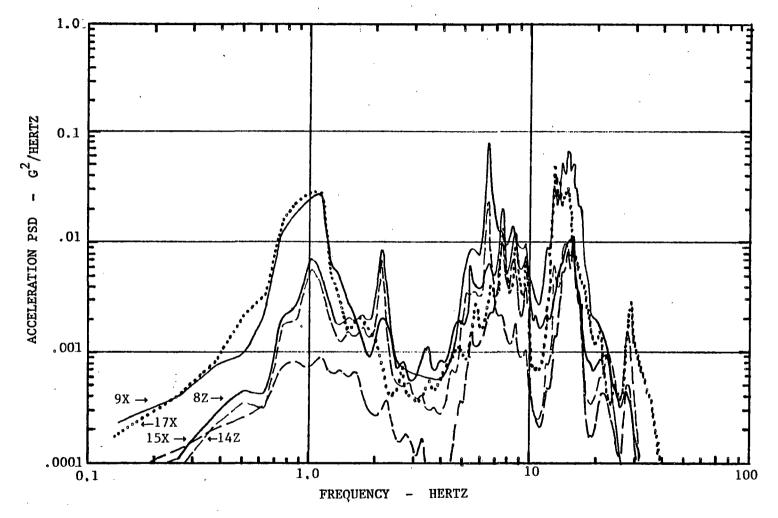


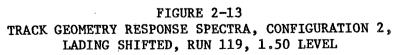


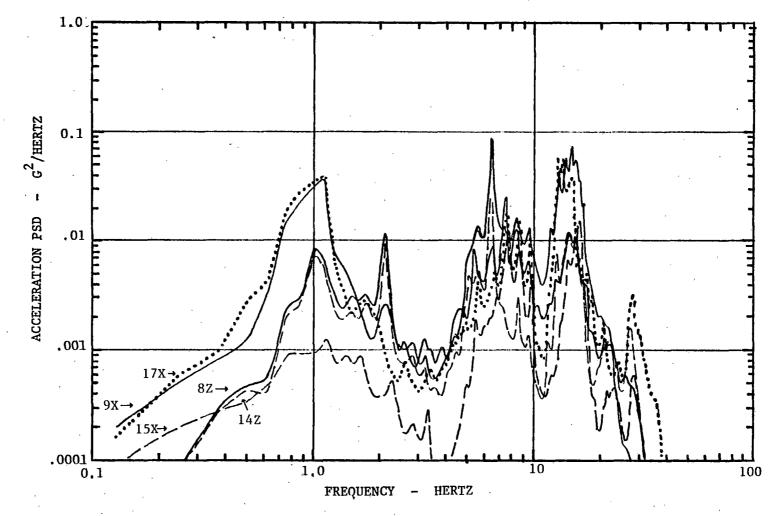


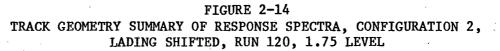












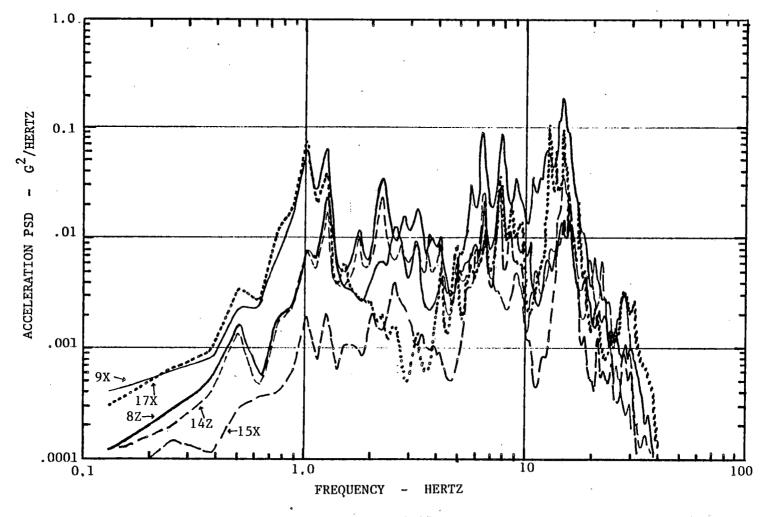


FIGURE 2-15 TRACK GEOMETRY SUMMARY OF RESPONSE SPECTRA, CONFIGURATION 2, LADING SHIFTED, RUN 121, 2.00 LEVEL

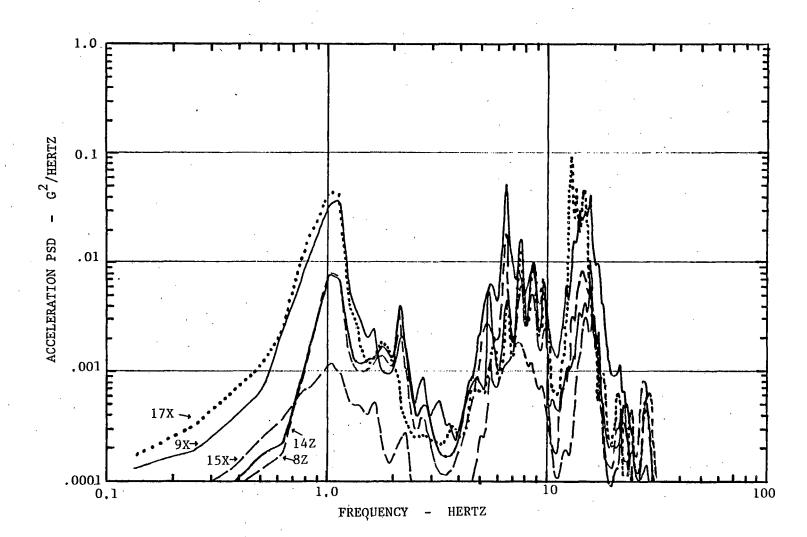
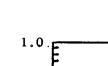


FIGURE 2-16 TRACK GEOMETRY RESPONSE SPECTRA SUMMARY, CONFIGURATION 2, LADING CENTERED, RUN 122, 1.25 LEVEL



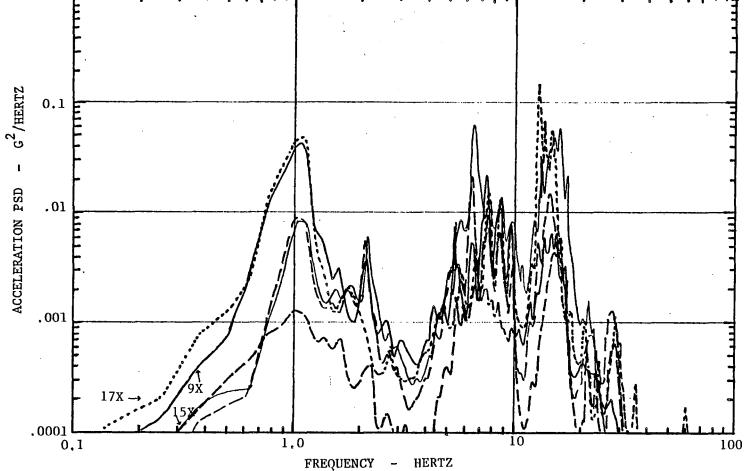
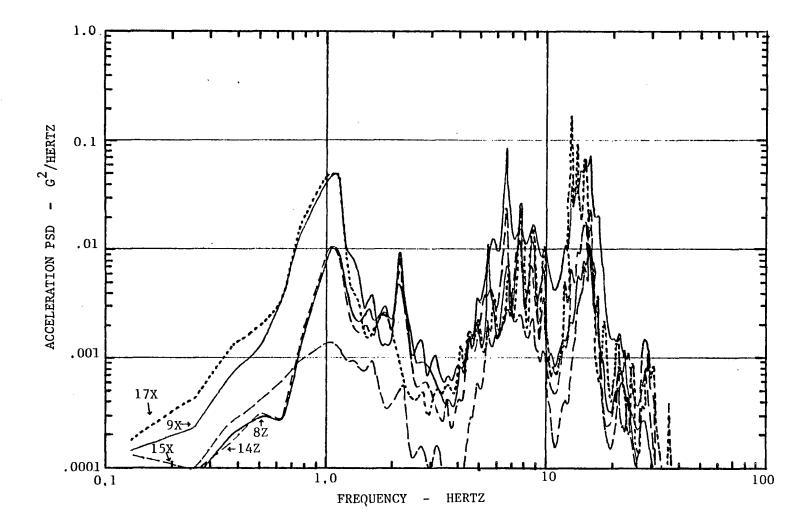
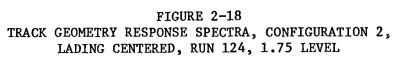


FIGURE 2-17 TRACK GEOMETRY RESPONSE SPECTRA SUMMARY, CONFIGURATION 2, LADING CENTERED, RUN 123, 1.50 LEVEL





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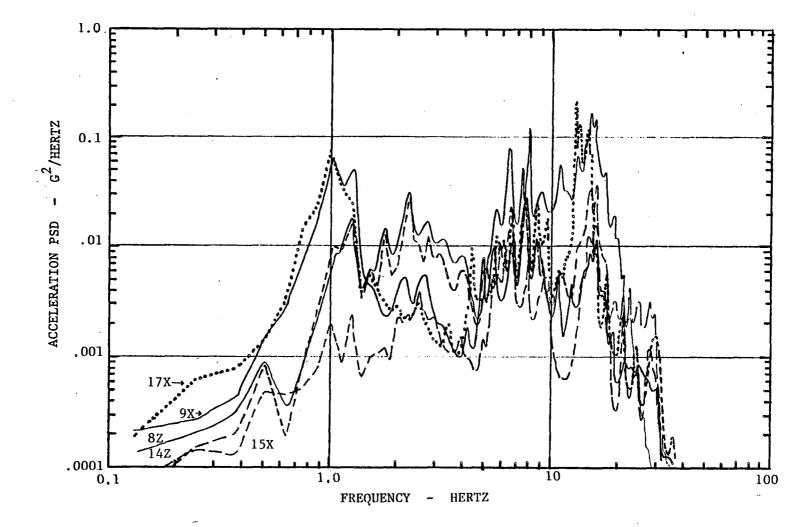


FIGURE 2-19 TRACK GEOMETRY RESPONSE SPECTRA, CONFIGURATION 2, LADING CENTERED, RUN 125, 2.00 LEVEL

3. POWER SPECTRAL DENSITY ENVELOPES

Envelope PSD plots were made for the three lateral (X) and two vertical (Z) acceleration measurements for the four test conditions covering configurations 1 and 2 with the lading centered and shifted. The objective for presenting the data in this form was to show representative X and Z levels of accelerations PSD as an aid to interpretations of the test results and for possible future reference.

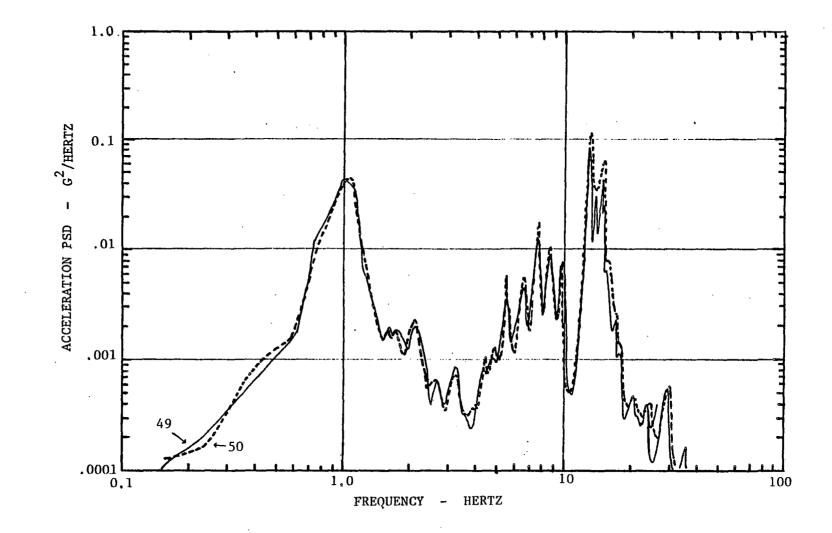
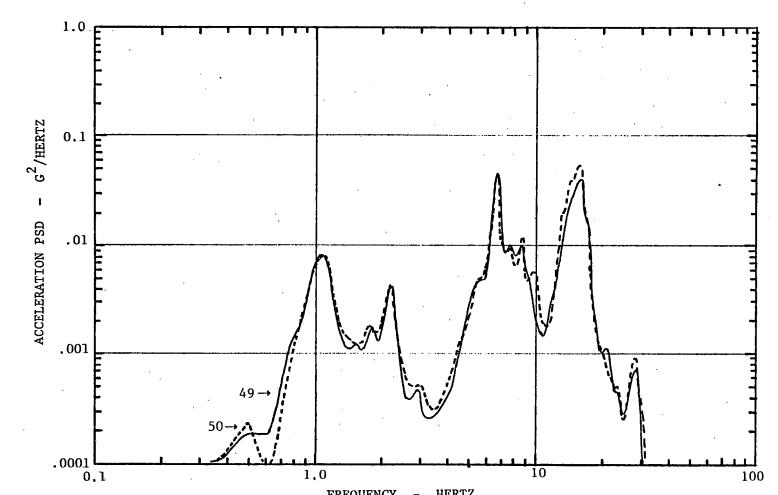


FIGURE 3-1 ENVELOP PSD OF X RESPONSES, CONFIGURATION 1, LADING CENTERED, TRACK GEOMETRY TESTS

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FIGURE 3-2 ENVELOP PSD OF Z RESPONSES, CONFIGURATION 1, LADING CENTERED, TRACK GEOMETRY TESTS

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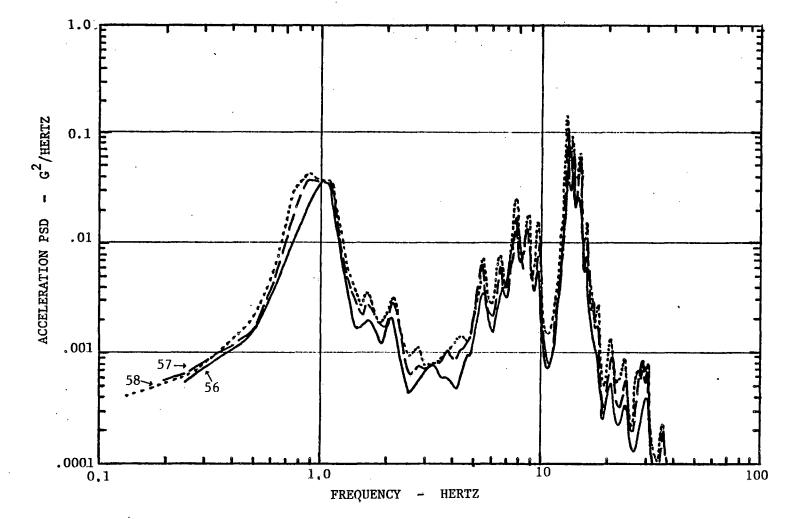


FIGURE 3-3 ENVELOP PSD OF X RESPONSES, CONFIGURATION 1, LADING SHIFTED, TRACK GEOMETRY TESTS

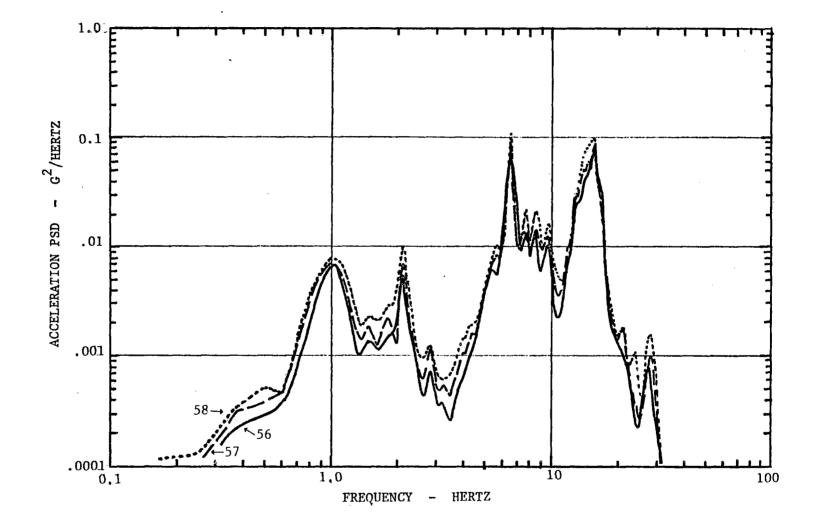


FIGURE 3-4 ENVELOP PSD OF Z RESPONSES, CONFIGURATION 1, LADING SHIFTED, TRACK GEOMETRY TESTS

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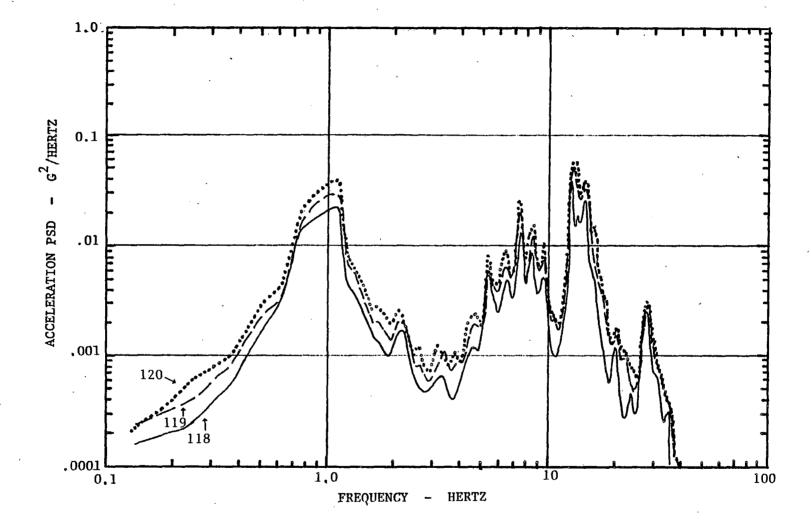


FIGURE 3-5 ENVELOP PSD OF X RESPONSES, CONFIGURATION 2, LADING SHIFTED, TRACK GEOMETRY TESTS

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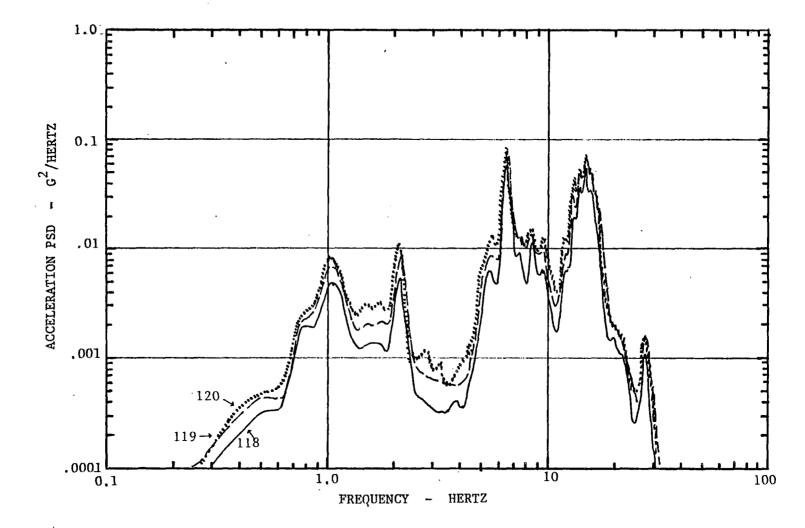
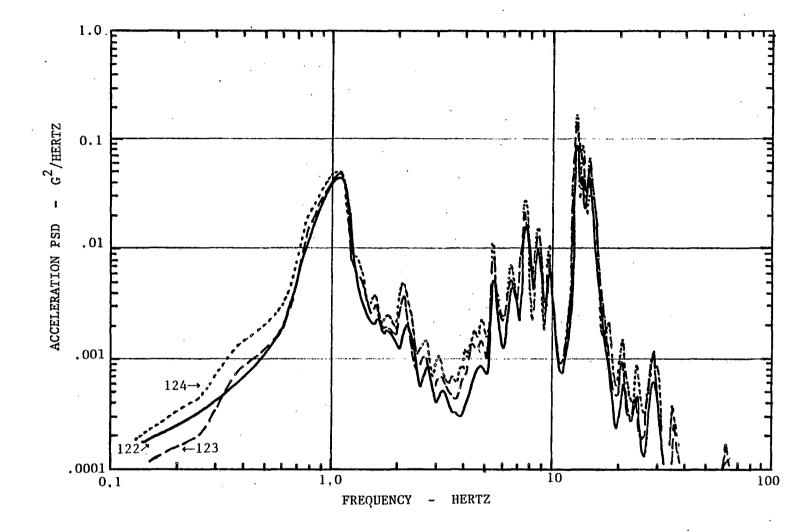
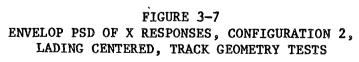


FIGURE 3-6 ENVELOP PSD OF Z RESPONSES, CONFIGURATION 2, LADING SHIFTED, TRACK GEOMETRY TESTS

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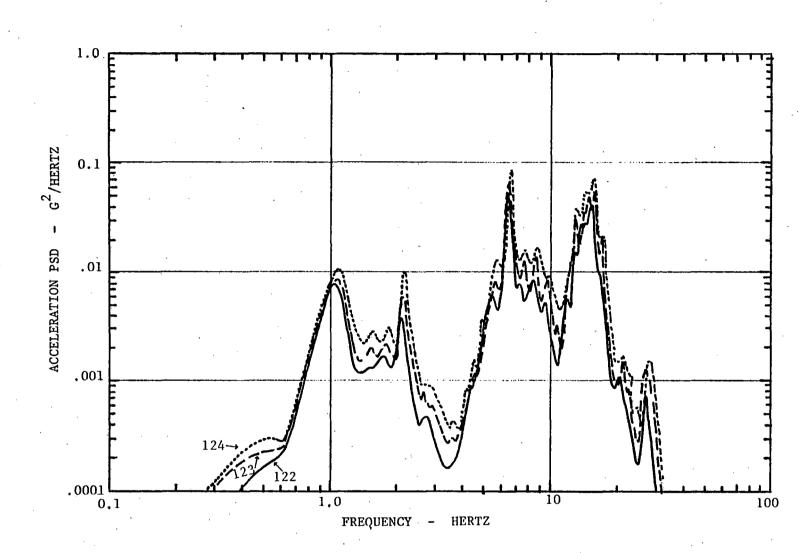


FIGURE 3-8 ENVELOP PSD OF Z RESPONSES, CONFIGURATION 2, LADING CENTERED, TRACK GEOMETRY TESTS

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4. COMPARISON OF CONFIGURATIONS 1 AND 2 IN TRACK GEOMETRY TESTS

The PSD spectrum for accelerometers 8AZ and 9AX were used to show the difference in responses of the plywood lading in configurations 1 and 2 in the lading centered and shifted conditions. No significant conclusions were drawn from this comparison, and the data is presented for reference purposes only.

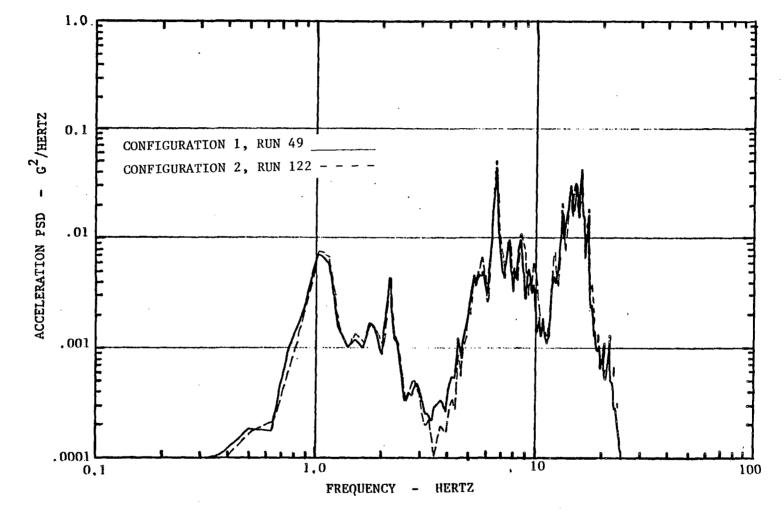
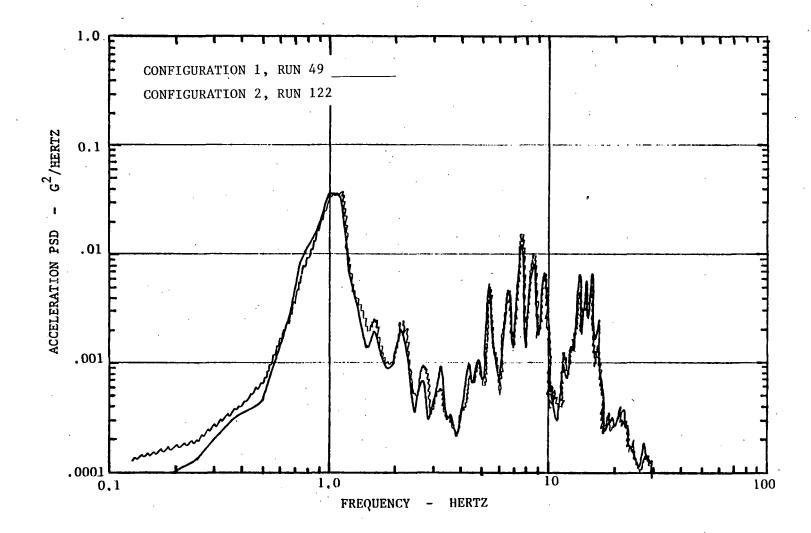
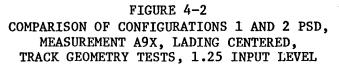
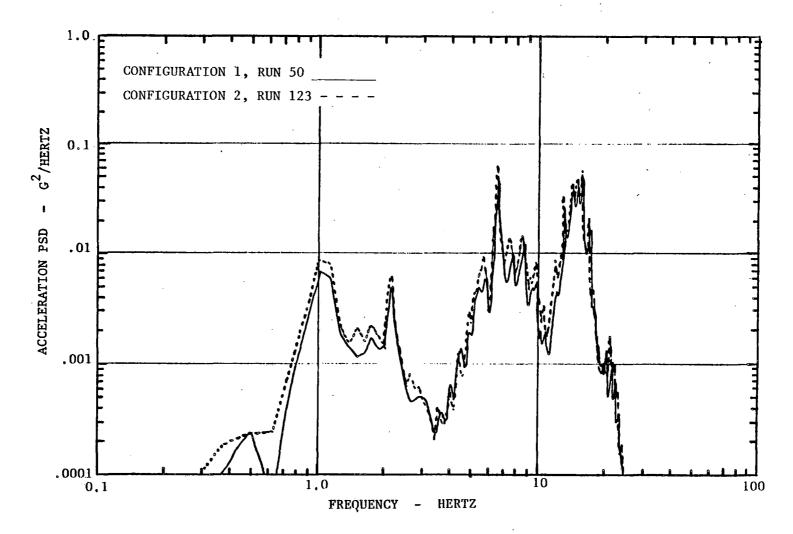
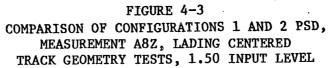


FIGURE 4-1 COMPARISON OF CONFIGURATIONS 1 AND 2 PSD, MEASUREMENT A8Z, LADING CENTERED, TRACK GEOMETRY TESTS, 1.25 INPUT LEVEL

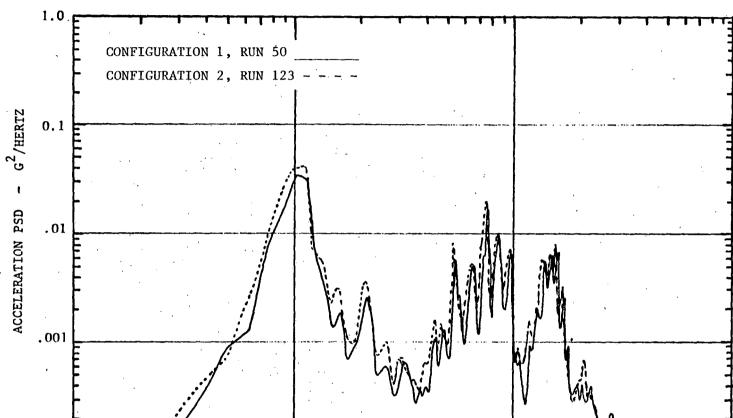








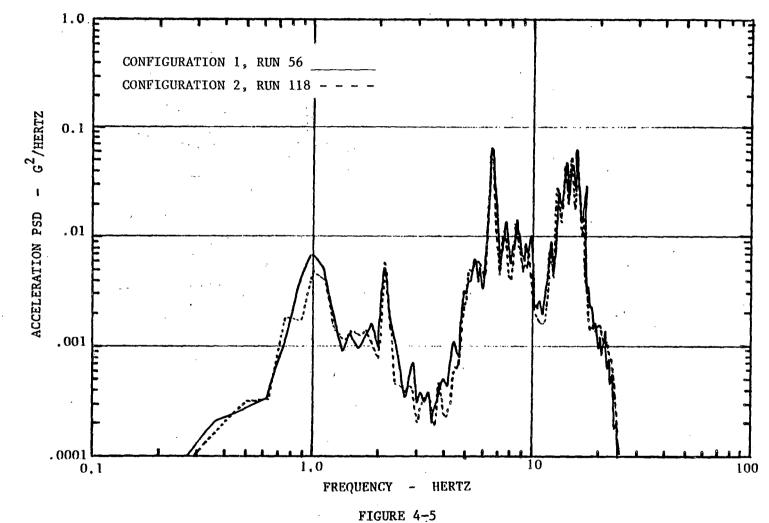
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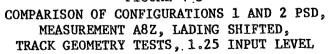


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COMPARISON OF CONFIGURATIONS 1 AND 2 PSD, MEASUREMENT A9X, LADING CENTERED, TRACK GEOMETRY TESTS, 1.50 INPUT LEVEL





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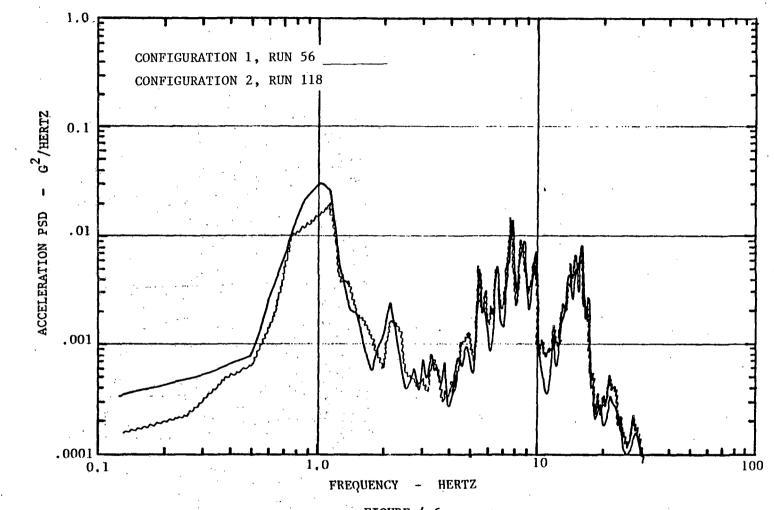
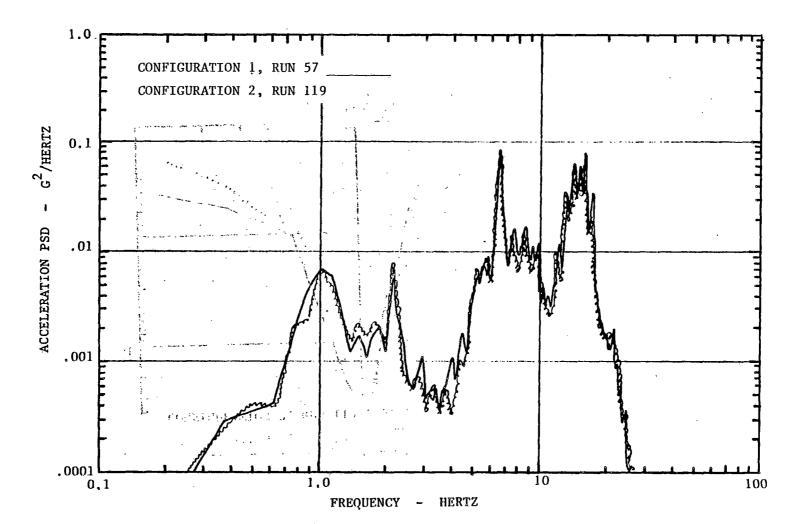
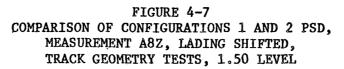


FIGURE 4-6 COMPARISON OF CONFIGURATIONS 1 AND 2 PSD, MEASUREMENT A9X, LADING SHIFTED, TRACK GEOMETRY TESTS, 1.25 INPUT LEVEL



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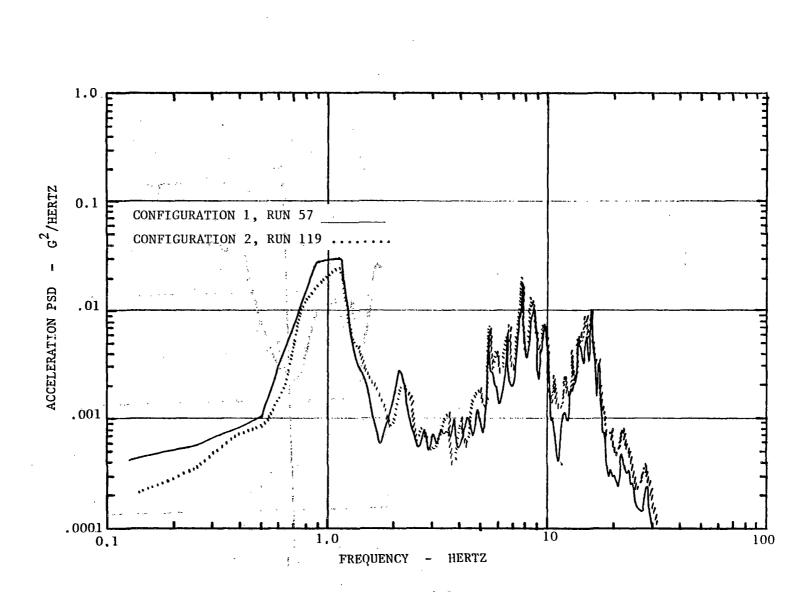


FIGURE 4-8 COMPARISON OF CONFIGURATIONS 1 AND 2 PSD, MEASUREMENT A9X, LADING SHIFTED TRACK GEOMETRY TESTS, 1.50 INPUT LEVEL

APPENDIX A

LIST OF REFERENCES

1. Harry A. Grosso, Vibrations Test Unit-Pilot Test, AAR Test Requirements, Association of American Railroads letter, January 27, 1982, File: G948.

2. George Kachadourian, FRA Test Requirements, VTU Pilot Test, MITRE Corporation Working Paper No. WP-82W00001, January 1982.

3. Wade D. Dorland et al, Implementation Plan, Rail Dynamics Laboratory, Vibration Test Unit Pilot Test, Report No. VTU-IP-82-03-03, March 1982.

4. Britto Rajkumar and Firdausi Irani, VTU Pilot Program, Validation of the Track Geometry Input to the Vibration Test Unit (VTU). Boeing Services International, Transportation Test Center, Pueblo, Colorado, July 26, 1982.

5. Britto Rajkumar and Firdausi Irani, Validation of the Vibration Test Unit Endurance Capability, Vibration Test Unit, Boeing Services International Transportation Test Center, Pueblo, Colorado, August 18, 1982.

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Safety Margin Testing of a 70-Ton Boxcar with Shifted Plywood Lading: Test Results Data, 1984 US DOT, FRA, George Kachadourian