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Truck Design Optimization Project Phase II

Guideline Test Specifications for Freight Car Trucks

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& Systems Group

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FRA/ORD - 81/36-II

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03 - Rail Vehicles &
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NOTICE

NOTICE

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16. Abstract

Under the Federal Railroad Administration-sponsored Truck Design Optimization Project Phase II, a set of standard test specifications were developed to evaluate and characterize the performance of Type I (standard) and Type II (premium) freight car truck configurations. The test specifications provide guidelines for the conducting, acquisition, and analysis of both field and laboratory testing, so that the resulting performance test data can be evaluated against the recommended levels of performance developed during Phase II efforts.

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test specifications, field tests, laboratory tests, performance regimes, lateral stability, trackability, ride quality, steady state curve negotiation, TDOP Phase II

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METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

LENGTH

Symbol	When You Know	Multiply by	To Find	Symbol
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km

AREA

Symbol	When You Know	Multiply by	To Find	Symbol
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha

MASS (weight)

Symbol	When You Know	Multiply by	To Find	Symbol
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t

VOLUME

Symbol	When You Know	Multiply by	To Find	Symbol
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3

TEMPERATURE (exact)

Symbol	When You Know	Multiply by	To Find	Symbol
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

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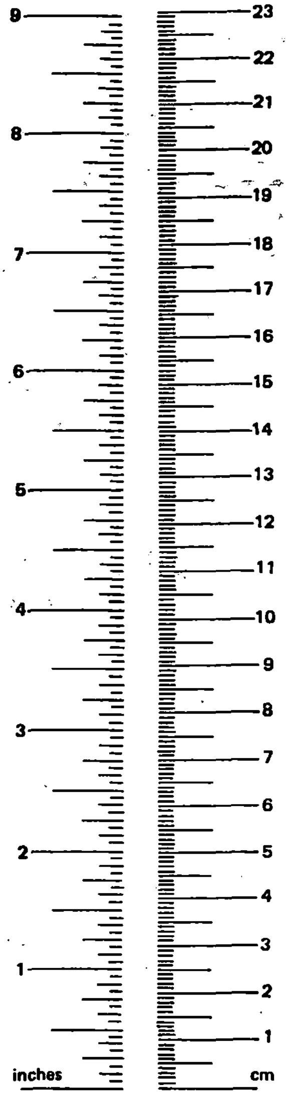
[*] 1 in. = 2.54 cm (exactly). For other exact conversions and more detail tables see NBS Misc. Publ. 286. Units of Weight and Measures. Price $2.25 SD Catalog No. C13 10 286.



Approximate Conversions from Metric Measures

LENGTH

Symbol	When You Know	Multiply by	To Find	Symbol
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi

AREA

Symbol	When You Know	Multiply by	To Find	Symbol
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	

MASS (weight)

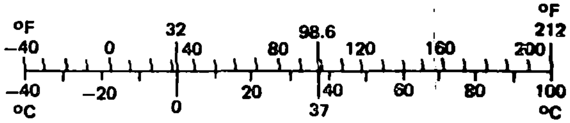
Symbol	When You Know	Multiply by	To Find	Symbol
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	

VOLUME

Symbol	When You Know	Multiply by	To Find	Symbol
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	36	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3

TEMPERATURE (exact)

Symbol	When You Know	Multiply by	To Find	Symbol
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



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SECTION 1 - INTRODUCTION

One of the objectives of the Truck Design Optimization Project (TDOP) Phase II is to develop a set of standard test specifications to evaluate and characterize the performance of Type I (standard) and Type II (premium) freight car truck configurations. The test specifications provide guidelines for the conducting, acquisition, and analysis of both field and laboratory testing, so that the resulting performance test data can be evaluated against the recommended levels of performance set forth in "Performance Characterization of Type I Freight Car Trucks" (Reference 1), and "Performance Specification for Type II Freight Car Trucks", (Reference 2).

Specification of performance for freight car trucks developed during TDOP/Phase II stipulate quantitative levels of performance characteristics expected of them under a given set of operating conditions. The overall performance of freight car trucks has been compartmentalized into four distinct and non-overlapping performance regimes (lateral stability, trackability, steady state curve negotiation, and ride quality); taken together, these four performance regimes are inclusive of the overall truck performance. In each of the performance regimes, ranges of economics-related engineering performance indices correlated to corresponding sets of operating conditions comprise the specification of performance. A detailed description of the performance regimes and associated performance indices is given in References 1 through 3.

Guideline test specifications provided herein set forth the procedures for, and conduct of, field tests (over-the-road tests) as well as laboratory tests for generating the performance test data which will be necessary for the quantification of the performance indices. These indices can then be used in a quantitative evaluation of performance of freight car trucks and a check on their compliance with the performance specification.

A road test represents the rail environment in all its complexity. This tends to lend credibility to the results which may be enhanced by direct observation of the test specimen. However, care should be taken that the road tests planned will be properly conducted, adequately instrumented, and rationally interpreted. The test track is defined in this report so that it can be duplicated. Laboratory tests, on the other hand, are accomplished under a controlled environment to conduct research on the many dynamic factors affecting vehicle performance and safety.

With this in mind, the Rail Dynamics Laboratory (RDL) facility at the Transportation Test Center in Pueblo was designed and constructed. The goal of RDL is to provide a facility to perform dynamic tests on several configurations of locomotives, cars and trucks under controlled conditions. Such a facility permits the evaluation of various hardware designs in a safe, controlled and reproducible scientific laboratory environment, allowing the performance of a variety of tests. While simulated tests under controlled conditions in the laboratory may not serve as a substitute for field tests, they can be effective and complementary tools used to augment the results from a field test program in a cost effective manner. Thus, the test specifications provided here include both field and laboratory test conditions.

SECTION 2 - SALIENT TRUCK PERFORMANCE CHARACTERISTICS

A railroad operating in mountainous territory is concerned primarily with performance of the vehicle system on curved track of relatively low speeds; whereas, a railroad operating in flat terrain has its dominant concerns relating to hunting performance on tangent track. Railroad handling fragile cargo may be concerned with the ride quality aspect of performance. Safety/stability of the vehicle system, e.g., harmonic roll, is the concern of all operators. Thus, the characterization of performance requires the identification of specific performance regimes (Reference 3), which may be defined as sets of conditions associated with predominant features that distinguish one regime from another. In order that the performance may be quantified, performance indices associated with each of the performance regimes are identified. The characterization of performance is represented by a range of quantified performance indices within each performance regime and associated with a specified set of operating conditions such as speed, lading, and track quality. The defined performance regimes and associated performance indices are described briefly below, and given in Table 1.

TABLE 1. TDOP TRUCK PERFORMANCE CLASSIFICATION

PERFORMANCE REGIME		PERFORMANCE INDEX
Lateral Stability		Critical Speed Peak Lateral Acceleration (Zero-to-Peak)
Ride Quality		Transmissibility (Vertical, Lateral, Roll) RMS Accelerations (Vertical, Lateral, Roll) - 0-20 Hz
Steady State Curve Negotiation		Average Lateral Force On Leading Outer Wheel Average L/V Ratio On Leading Outer Wheel Average Angle-of-Attack Of Leading Axle
Trackability	Harmonic Roll	Critical Speed Peak Roll Angle (Zero-to-Peak)
	Bounce	Critical Speed Peak Vertical Acceleration (Zero-to-Peak)
	Track Twist	Wheel Unloading Index* (95th Percentile)
	Curve Entry/Exit	Wheel Unloading Index (95th Percentile)

* Wheel Unloading Index WUI = $1 - W_L/(W_H/3)$,

where,

W_L is the vertical force on most lightly loaded wheel

W_H is the sum of vertical forces on the threemost heavily loaded wheels

2.1 LATERAL STABILITY

Lateral stability is the term used to describe the capability of a truck to inhibit self-induced lateral and yaw oscillations known as hunting. Hunting may be exhibited either by the truck alone, or by more complex interactions involving both trucks and carbody. Hunting is a safety, as well as operation, problem. High-speed derailment, gauge widening, lading damage, and accelerated vehicle components and rail wear are known to result from the hunting phenomenon.

Performance indices, or measureable physical characteristics unambiguously associated with performance, identified within the lateral stability regime are:

- Critical speed of hunting (determined by root mean square lateral acceleration)
- Peak lateral acceleration

2.2 TRACKABILITY

Trackability is the ability of the truck to maintain sufficient loads on all wheels to allow the development of guidance forces which prevent derailment for all extremes of in-service track geometry. The trackability regime includes as subsets the ability of the truck to accommodate: (a) harmonic roll and bounce dynamics, (b) track twist, (c) curve entry/exit.

Harmonic roll is a forced response resonance problem with the carbody responding with large amplitude, low center roll motions. The resonance problem is normally encountered on jointed rail track while the car is at speeds in the 10 to 20 mph range. Excessive carbody roll can result in side-bearing contact, bottoming of the main suspension springs, and, ultimately, wheel lift-off and complete car rollover. The primary concern of the harmonic roll problem is one of safety although component deterioration, such as snubber wear and truck bolster failure, also occurs. Some lading damage may also be attributed to harmonic roll. The performance indices for harmonic roll are critical (resonant) speed and peak roll angle.

Bounce dynamics include carbody vertical and pitch motions. Bounce resonances are particularly a problem with shorter cars (around 20 ft in length). Car lengths that do not correspond to the rail length receive vertical and pitch as well as roll excitation. Bounce occurs at a higher speed than harmonic roll since the carbody pitch is a higher frequency mode than the roll mode (typically 3 to 5 Hz versus 0.7 to 1.8 Hz). At speeds around 40 to 65 mph, the vertical excitation from the half-staggered rail corresponds to the pitch mode natural frequency of 3 to 4 Hz. Both safety and component deterioration are concerns of this regime. The performance indices identified for bounce subregimes are critical (resonant) speed and peak vertical acceleration.

The ability of the truck to accommodate track twist refers to the maintenance of adequate wheel loads in the presence of cross level variations occurring within the wheelbase of the truck. This ability is important for successful negotiation of low sidings and extremely poor track in switchyards. The wheel unloading index (peak value or 95 percentile) is used to quantify the track twist subregime.

During curve entry and exit, the car and truck experience forces and motions which can impart extreme dynamic response to the carbody and truck. Excessive harmonic roll and flange contact can occur, resulting in wheel unloading and wheel climb in extreme situations. The truck must be able to maintain a smooth transition from the tangent to the curve track for a wide range of operating conditions and environmental factors. The performance index identified to quantify the curve entry and exit is the wheel unloading index (peak value or 95 percentile).

2.3 STEADY-STATE CURVE NEGOTIATION

As a train negotiates a constant curvature segment of track at more-or-less steady speed, horizontal forces at the contact planes between the wheels and the rails work to rotate and guide the vehicle around the curved track. Since most truck designs are limited in their ability to permit individual axles to align themselves radially in the curve, this results in the wheel flanges making contact with the rails. Therefore, the trucks often rely on flange contact to provide guidance in curves. The consequences of these lateral forces are wheel and rail wear, resistance of the truck to forward motion resulting in increased demands on tractive power and therefore increased fuel consumption, and, in extreme cases, the tendency for wheels to climb the rails thus giving rise to the potential of derailment. The performance indices identified with this regime are:

- Average lateral force on leading outer wheel
- Average lateral-to-vertical force ratio (L/V ratio) on the leading outer wheel
- Average angle of attack

2.4 RIDE QUALITY

The ride quality regime includes all non-extreme car/truck dynamics. The freight car and truck dynamics during normal operation with the carbody and truck responding to track inputs with no abnormal or extreme motions (e.g., hunting, harmonic roll, or bounce) are of concern within the ride quality regime. The characteristics of a truck to function as a mechanical filter in isolating the carbody from the disturbances induced by the track are of primary interest in this performance regime.

The principal performance index identified in this regime is transmissibility, defined here as the ratio of the rms value calculated from the response power spectral density within a specified frequency bandwidth to the rms value calculated from the truck input power spectral density over a corresponding frequency bandwidth. Transmissibility can be quantified for vertical, lateral, and roll motions of the carbody, with the corresponding track input arising from track profile, alignment, and cross level. Additionally, the rms response over a wide band spectrum (0-20 Hz) can be identified as a supplementary index. This index reflects the level of energy content in the oscillatory motions of the carbody and provides a means for comparison of the ride quality of various vehicle configurations under equivalent conditions of operation.

SECTION 3 - TEST EQUIPMENT

The evaluation of performance test data of freight car trucks against the recommended levels of performance requires that the variables affecting the dynamic behavior of such trucks be controlled and reduced, so that the evaluation and comparison can be meaningful without resorting to unnecessary assumptions. For the test equipment, the most important variables are carbody types and wheel profiles. This section, thus, describes briefly the carbodies and wheel profiles used in generating the test data during Phase I and II of the Truck Design Optimization Project. A complete description can be found in References 1, 2, and 4.

In Phase I of the Truck Design Optimization Project, different types of cars equipped with different combinations of standard Type I trucks and wheel profiles (Reference 4), were tested. The cars tested were a 70-ton mechanical refrigerator car, a 70-ton box car, long low-level flat car, a 100-ton box car, and a 100-ton covered hopper car. The characteristics of these cars are given in Table 2. Wheel profiles used in Phase I test program, data from which were used in quantifying prformance characterizations under the Phase II effort, are new AAR 1:20 and worn profiles. Typical wheel profiles are given in Figures 1 and 2.

Phase II of the Truck Design Optimization Project consisted of testing a number of Type I and Type II trucks under open hopper cars. New AAR 1:20 and new CN wheel profiles were used in testing. The carbody characteristics are given in Table 3. A comparison between the CN profile wheel and AAR 1:20 profile wheel is shown in Figure 3.

To evaluate the relative performance of freight car trucks, they shall be tested with similar carbodies of one or more types, e.g., covered hopper, open hopper, box car, etc., on similar wheel profiles. In using the guideline levels of performance given in References 1 and 2, the carbody characteristics and wheel profiles used in the proposed truck testing shall be comparable with the corresponding ones used in generating those guidelines. The tests shall be conducted with both empty and fully loaded carbodies. The lading for the cars are arbitrary, provided that all trucks tested shall be loaded identically. The center of gravity shall be determined accurately especially for testing harmonic roll.

Test consist shall be standard on all test runs. A recommended consist includes a locomotive, data acquisition car, buffer car, test car, buffer car, and a caboose, in that order. The buffer cars shall preferably be the same type of carbody used in the test configuration and the buffer car shall be loaded for use in all test runs.

TABLE 2. CARBODY CHARACTERISTICS (PHASE I)

	70-Ton Capacity Mechanical Refrigerator Car	70-Ton Capacity General Service Boxcar	70-Ton Capacity Long Low-Level Flatcar	100-Ton Capacity Auto-Parts Boxcar	100-Ton Capacity Covered Hopper Car
Light Weight, lb	89,100	61,200	56,300	87,300	64,500
Capacity, lb	130,900	154,000	122,000	174,000	197,500
Length Over Pulling Face of Coupler, ft	63.70	55.38	93.67	68.25	54.29
Truck Centers, ft	45.72	40.00	64.00	46.25	40.83
Car Wheel Base, ft	51.39	46.83	69.08	52.08	46.25
Overhang, ft	9.00	7.29	14.83	11.00	7.29
Center of Gravity-Loaded, ft	7.33	7.03	7.17	7.83	7.03
Center of Gravity-Empty, ft	5.55	4.58	1.97	5.17	4.58
Centerplate Diameter, ft	1.17	1.17	1.17	1.33	1.25

TABLE 3. CARBODY CHARACTERISTICS (PHASE II)

	70-Ton Capacity* Open Hopper Car	100-Ton Capacity Open Hopper Car
Empty (light) weight, lb	44,700	67,300
Loaded weight, lb	167,900	237,300
Capacity, lb	154,000	196,000
Length over pulling face of coupler, ft	46.17	53.04
Truck centers, ft	33.67	40.5
Center of Gravity (above rail):		
Loaded, ft	5.85	7.17
Empty, ft	-	4.38

*Used only on Alusuisse truck testing.

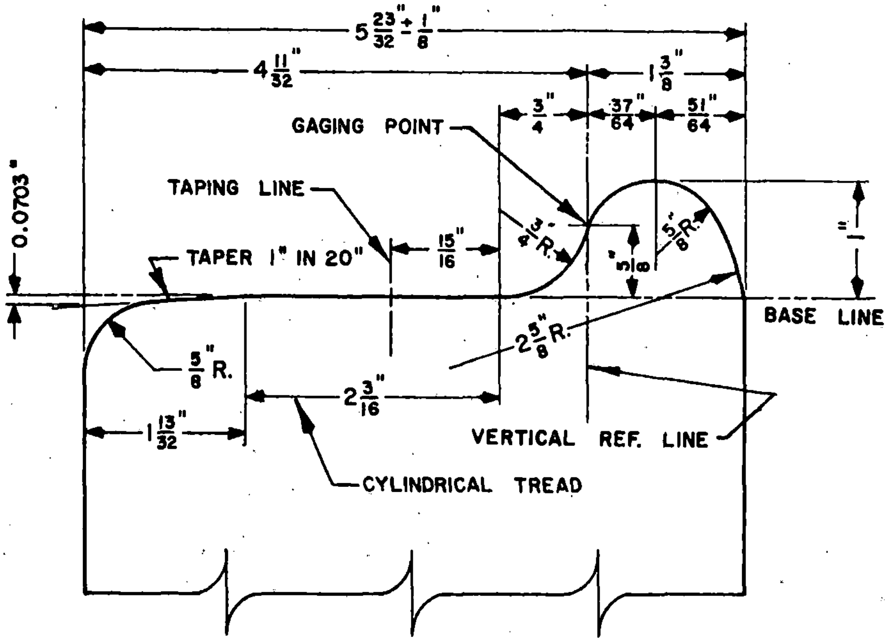


FIGURE 1.a. CJ-36 TDOP CYLINDRICAL WHEEL PROFILE (REFERENCE 4)

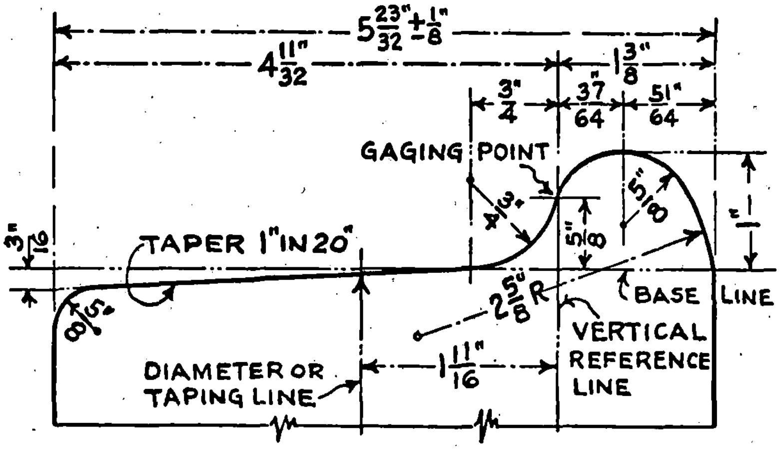
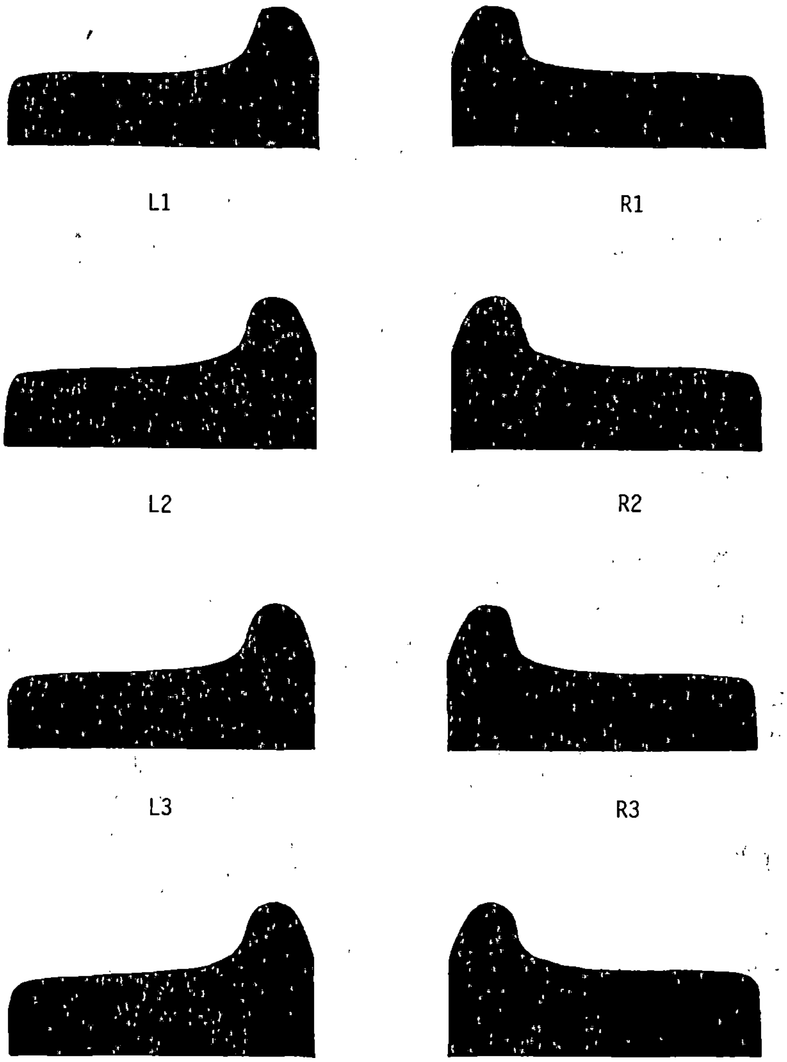


FIGURE 1.b. CM-33 - 1:20 TAPER PROFILE WHEELS (REFERENCE 4)



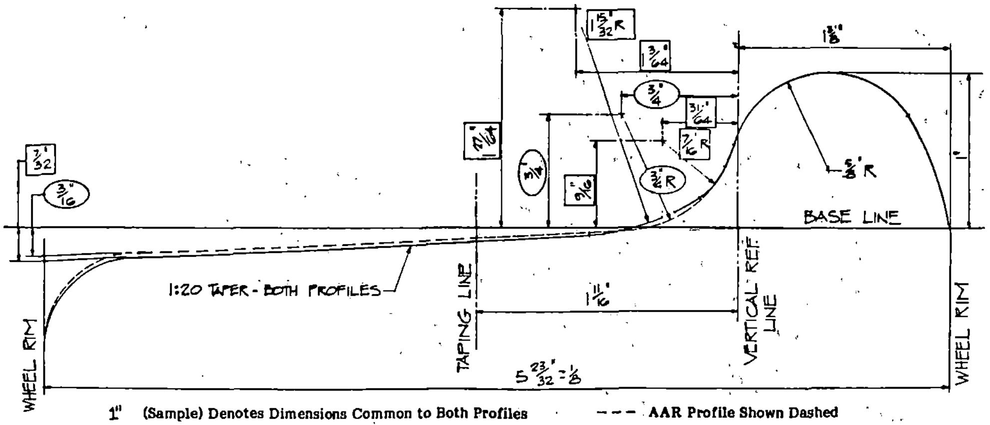
L1 R1

L2 R2

L3 R3

L4 R4

FIGURE 2. WORN WHEEL PROFILES (REFERENCE 4)



1" (Sample) Denotes Dimensions Common to Both Profiles

(1") AAR Profile Dimensions Only

[1"] CN Profile Dimensions Only

- - - AAR Profile Shown Dashed

—— CN Profile

FIGURE 3. WHEEL PROFILE COMPARISON - CN PROFILE VERSUS AAR STANDARD 1:20 PROFILE

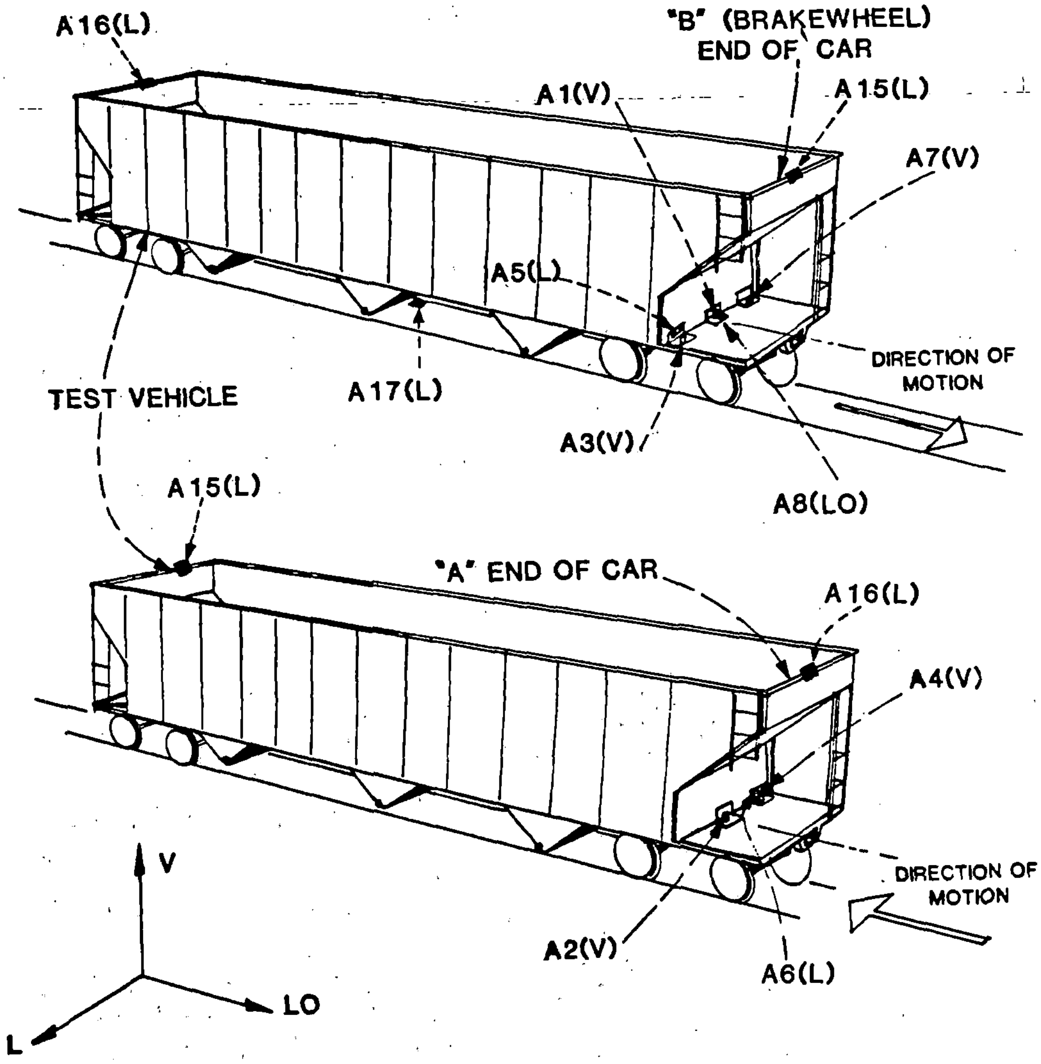
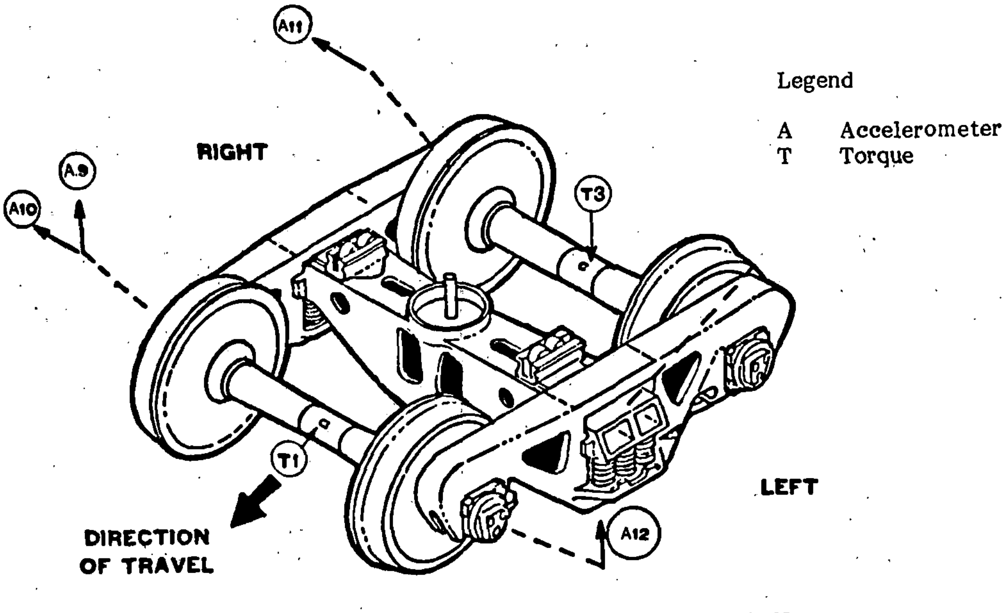


FIGURE 4. CARBODY INSTRUMENTATION



Legend

A	Accelerometer
T	Torque

FIGURE 5. TRUCK INSTRUMENTATION LOCATION

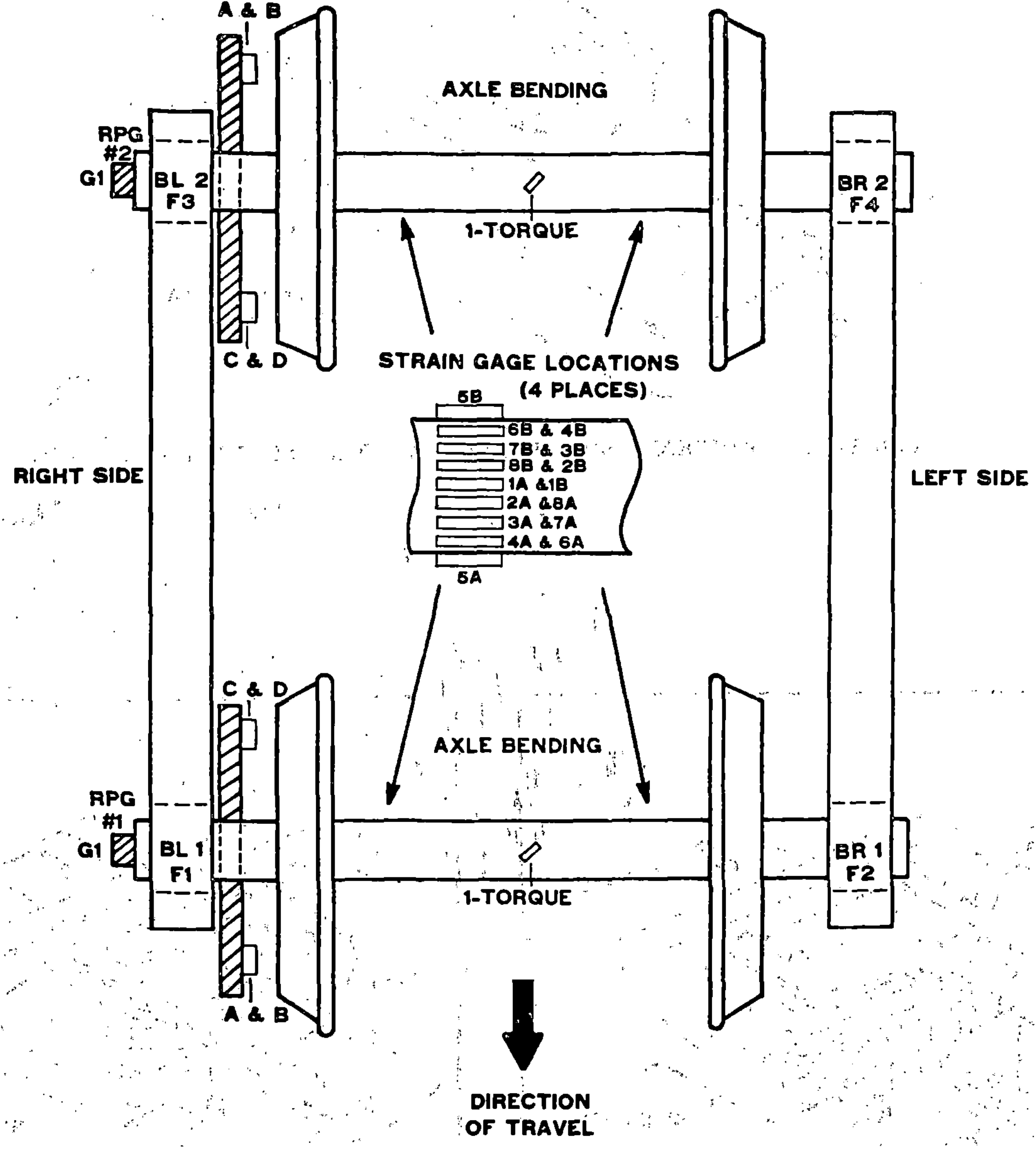


FIGURE 6. WHEEL/RAIL MEASUREMENT INSTRUMENTATION

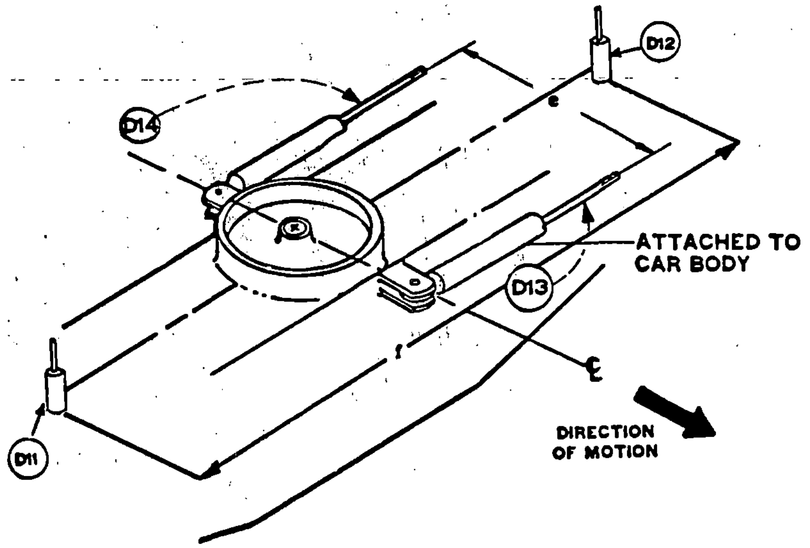
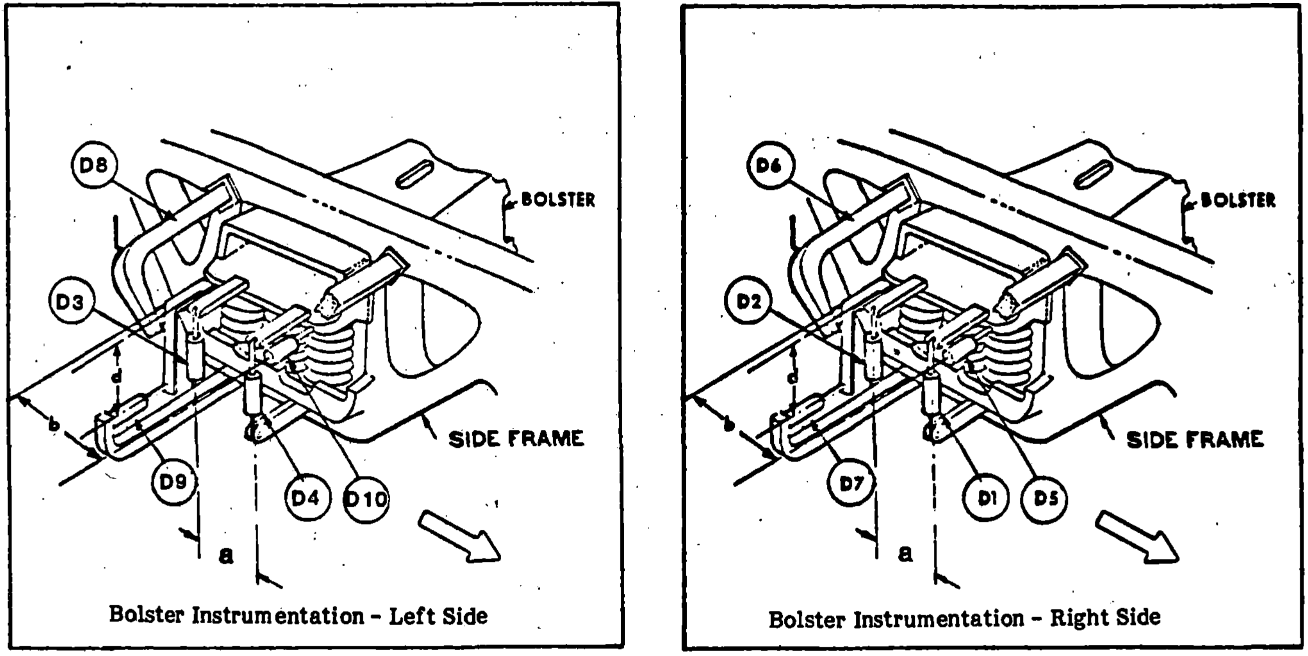


FIGURE 7. TRUCK/CARBODY RELATIVE MOTION INSTRUMENTATION (SWIVEL)



Bolster Instrumentation - Left Side

Bolster Instrumentation - Right Side

FIGURE 8. TRUCK DISPLACEMENT TRANSDUCERS (TRAM)

SECTION 4 - FIELD TEST SPECIFICATIONS

The specifications reported here cover field testing for freight car trucks in the four performance regimes of lateral stability, trackability, steady state curve negotiation, and ride quality. Under each regime, the data requirements, instrumentation, operating conditions, test procedure, and data reduction and analysis will be specified.

4.1 LATERAL STABILITY

a. Data Requirements and Instrumentation

Acceleration data shall be acquired at these locations:

Lateral accelerations at the B-end, A-end, and the center of the carbody at the sill level; at the B-end and the A-end on the carbody at the roof level; at each of the axles on both trucks under the carbody. Figures 4 and 5 show typical locations of the accelerometers.

The acceleration data acquired through accelerometers at these locations shall meet the following minimum criteria:

Frequency response: 20 Hz
Range of measurements: ± 10 g's
Accuracy of measurements: 1%

b. Test Track

Lateral stability data shall be acquired on test runs over tangent track which permits the acquisition of data over a speed range from 30 mph to 79 mph or the operating speed limit, whichever is higher. (Note: the 79 mph limit is chosen on the basis of current legal speed limits on mainline tracks.) The tangent track may be bolted, jointed, or continuous welded track, but the jointed track is recommended for testing since it represents a rough roadbed that may excite (initiate) the truck hunting movements.

c. Test Procedures

Tests shall be conducted on a selected segment of track of sufficient length (recommended length: a minimum of five miles, and more if possible) to permit the acceleration of the test consist from 30 to 79 mph and also to provide dwell times at incremental speeds of 5 mph throughout this range. The dwell times at each incremental speed, namely 30, 35, ...70, 75, and 79 mph, shall be a minimum of 60 seconds to provide acquisition of quality data at these selected constant speed intervals. If the length of test track does not permit this sequence of data acquisition in one pass, the test run shall be segmented into two, or more passes covering, say, for example 30 to 60 mph, 60 to 70 mph, and 70 to 79 mph as overlapping passes.

d. Data Reduction and Analysis

The output of the lateral accelerometers shall be examined using time history plots to identify the hunting phenomenon. The rms and the peak values of the collected data shall be determined and plotted as functions of vehicle speed.

4.2 TRACKABILITY

4.2.1 Harmonic Roll and Bounce

All requirements relating to data acquisition, instrumentation, test conditions, and test procedures shall be in accordance with "Specifications for Testing Special Devices to Control Stability of Freight Cars," Association of American Railroads Standard, adopted, 1968, and revised 1976, effective March 1, 1976 (Reference 5).

4.2.2 Track Twist

a. Data Requirements and Instrumentation

Simultaneous measurement of vertical forces at all wheel/rail interfaces on a given truck shall be accomplished through force measurement transducers. Although a combination of strain gauge axles and bearing adapters has been used for the purpose in arriving at the results presented in the Truck Design Optimization Project Phase II reports (Reference 1 & 2), other acceptable methods of wheel/rail force measurements may be used provided that such methods have been validated to assure that they yield data within acceptable limits of accuracy, namely 5%. Properly calibrated instrumented wheels may be used as force transducers to provide acceptable force measurement data. If only one of the two trucks under a car is instrumented, it shall be the forward truck; preferably, both trucks shall be instrumented to obtain vertical force measurements at all wheel/rail interfaces under the test car. Typical wheel/rail measurement instrumentation is shown in Figure 6.

b. Test Track

Ideally, the tests should be performed on track with known or available information on track twist. Examples may be simulated tracks or perturbed tracks with known measures of track twist introduced into them. Otherwise, tests shall be conducted on existing Class 1 tracks (yards) at speeds of 10 mph or less.

c. Test Procedures

Tests shall be conducted over the selected test track sections at an operating speed of 10 mph or less. Data shall be continuously recorded during the test runs.

d. Data Reduction and Analysis

The data for the vertical forces at the wheels of the trucks shall be examined, and the Wheel Unloading Index, Table 1, shall be calculated.

4.2.3 Curve Entry and Exit

Test runs and conditions governing the tests for acquisition of data to be used in this performance subregime are covered under subsection 4.3.

4.3 CURVE NEGOTIATION

a. Data Requirements and Instrumentation

Data requirements under this section, in addition to the steady state curve negotiation performance regime, also cover the curve entry/exit subregime of the trackability performance regime.

Continuous measurement of lateral and vertical forces at the wheel/rail interfaces (preferably all locations under the test car; at a minimum all locations at the forward truck under the test car) shall be performed. The force measurements may be accomplished by means of instrumented wheelsets where the axles are strain-gaged to record axle-bending moments and the bearing adapters are strain-gaged to measure vertical forces, with the forces calculated through the axle-bending technique (Reference 6); alternately, instrumented wheel plates may be used as force transducers to measure wheel/rail lateral and vertical forces.

Measurement of the wheel/rail angle of attack shall be performed. The angle of attack can be measured using a wayside system or vehicle-borne (onboard) system. The onboard system is recommended since it provides a continuous measurement of the angle of attack of the wheel with the rail during the negotiation of the curve. The onboard system can be electrical (non-contacting proximity sensors), or mechanical (spring-mass system). However, care should be taken to provide sufficient dynamic range for the system used in measuring the angle of attack. This is recommended in order to measure the angle of attack on both sides of the wheelsets of the leading truck.

Measurements of the truck swivel and track tram are recommended since they will help in reducing and analyzing the data (see Figures 7 and 8).

b. Test Track

Curve negotiation test runs shall be conducted on mainline (class 4 or better) test tracks consisting of curves ranging, at a minimum, from 2 to 6 degrees. A larger range of track curvature shall be desirable. The test track shall be selected so as to allow representation of at least one curve each in the classes of approximately 2,3, 4, 5, and 6 degrees, both right-hand and left-hand curves; the test curves shall be preceeded by a length of tangent track not less than that which permits the test train to accelerate or decelerate and enter the test curves at specified test speeds.

c. Test Procedures

A minimum of three test runs shall be conducted in each direction on the test track, representing (a) a test speed at least 5 mph below, but not more than 10 mph below, the equilibrium speed for each curved segment of track represented in the test zone; (b) at test speed equivalent to the equilibrium speed for each curved segment of track represented in the test zone; and (c) a test speed at least 5 mph above, but not more than 10 mph above, the equilibrium speed for each curved segment of track represented in the test zone, with a tolerance of ± 2 mph on the test speed being permissible. No brake applications are to be made during the test runs. Data generated during the test runs shall be acquired and recorded continuously. The equilibrium speed shall be calculated using the average curvature and superelevation determined by track geometry measurements on the steady state portion of the curve.

d. Data Reduction and Analysis

The time history of the data channels shall be examined. Lateral and vertical forces and L/V ratios, as well as angle of attack shall be calculated, and then plotted as functions of speed (or superelevation deficiency) and the degree of curvature.

4.4 RIDE QUALITY

a. Data Requirements and Instrumentation

Lateral and vertical acceleration data shall be acquired at least at the B-end, A-end, and carbody center at sill level. Lateral acceleration data shall be acquired at the B-end and A-end on the carbody at the roof level (Figure 4).

The acceleration data acquired through accelerometers shall meet the following minimum criteria:

Frequency response: 20 Hz
Range of measurements: ± 10 g's
Accuracy of measurements: 1%

b. Test Track

Ride quality data shall be acquired on test runs over Class 4, mainline tangent track (jointed welded rail) which permits the acquisition of data over a speed range from 30 to 79 mph. The track geometry data shall be acquired in order to correlate response measurements made on test vehicles with a known track input and to calculate the transmissibility. The track geometry data of interest in the study of ride quality are profile, alignment, gauge, and cross level. Typical power spectral densities of the track geometry parameters are shown in Figures 9 through 16.

c. Test Procedures

The test speeds shall range from 30 to 79 mph with 5 mph increments. Sample time of each speed shall be 60 seconds. The data shall be recorded continuously at each speed dwell.

d. Data Reduction and Analysis

Detailed statistical analysis shall be performed on the test data. The analysis shall include calculations of the frequency content of the data, the rms-values of the output signals and the track input, and the percent of the time a signal amplitude is above a given level as a function of that level. The transmissibility between the output signal and the track excitation should be calculated (the track excitation applied at the leading wheel of the leading truck can be used as a reference). This transmissibility may be characterized by a frequency dependent function of amplitude ratios called a transfer function, or a sequence of root mean square (rms) ratios of output-to-input over selected frequency bands (for example, 0-4 Hz, 4-10 Hz, and 10-20 Hz).

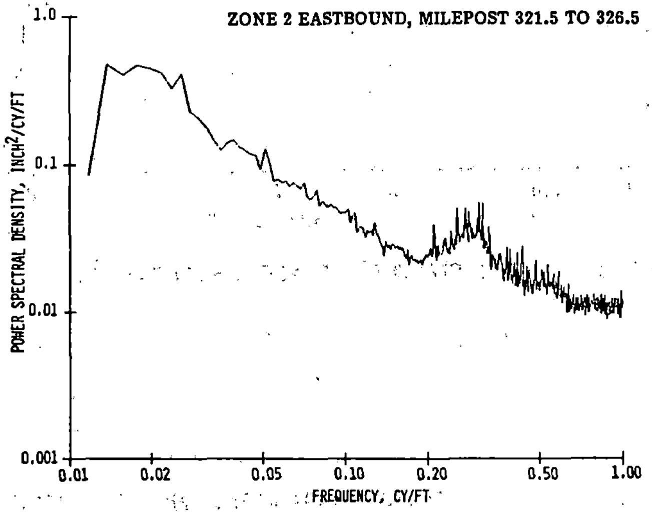


FIGURE 9. POWER SPECTRAL DENSITY - ZONE 2, AVERAGE ALIGNMENT

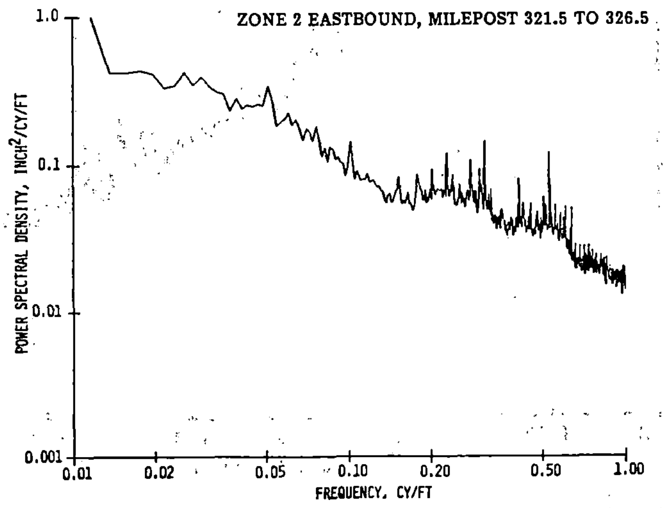


FIGURE 10. POWER SPECTRAL DENSITY - ZONE 2, GAUGE

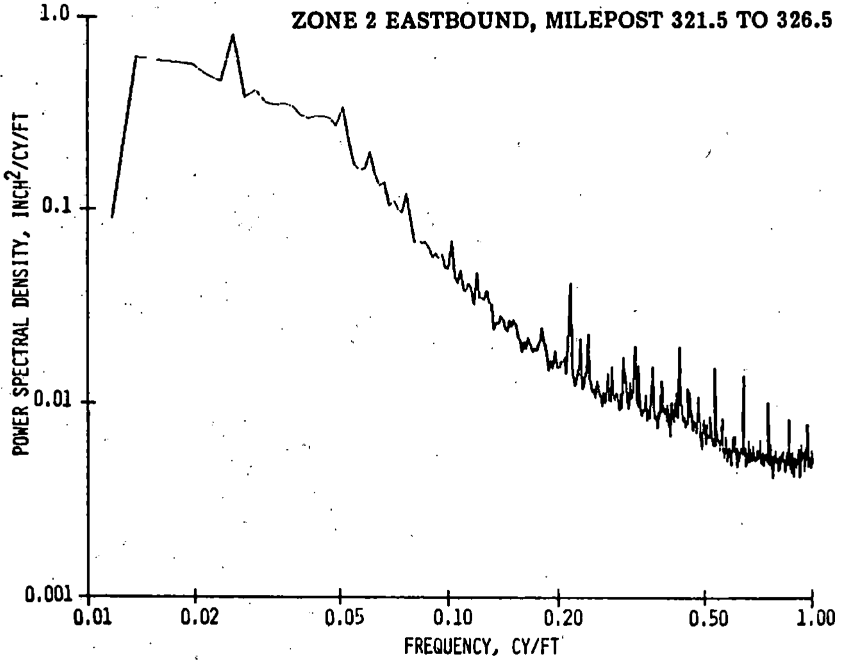


FIGURE 11. POWER SPECTRAL DENSITY - ZONE 2, AVERAGE PROFILE

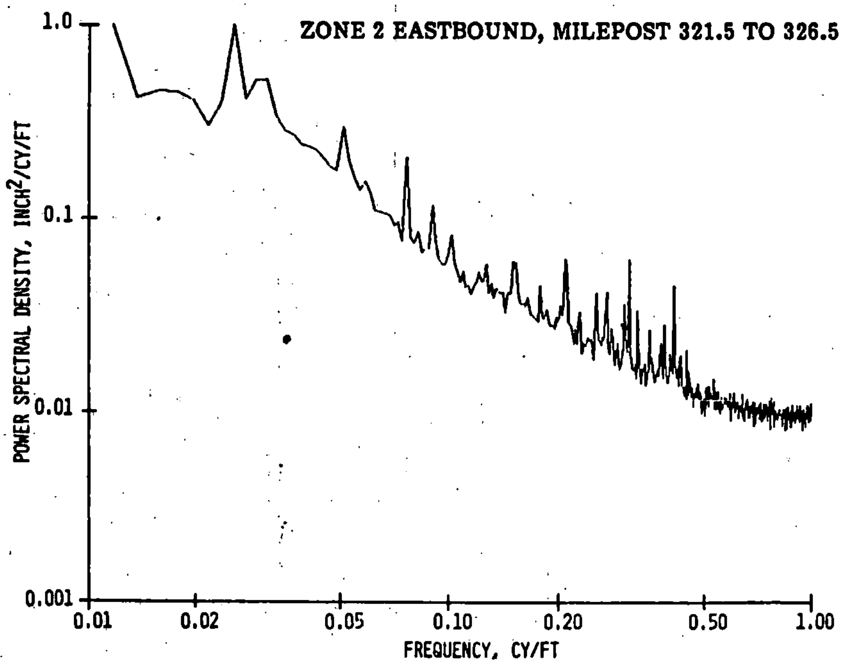


FIGURE 12. POWER SPECTRAL DENSITY - ZONE 2, CROSS LEVEL

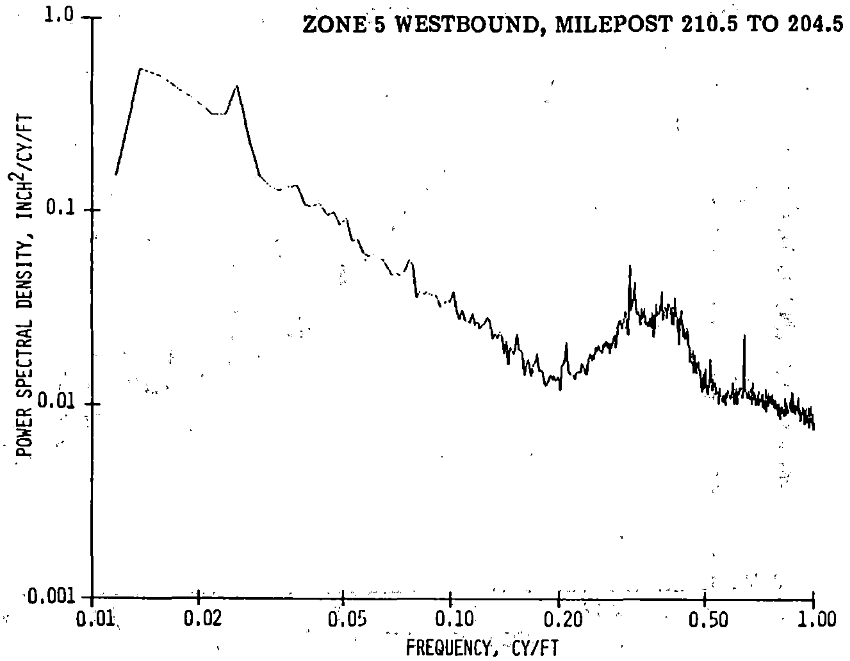


FIGURE 13. POWER SPECTRAL DENSITY - ZONE 5, AVERAGE ALIGNMENT

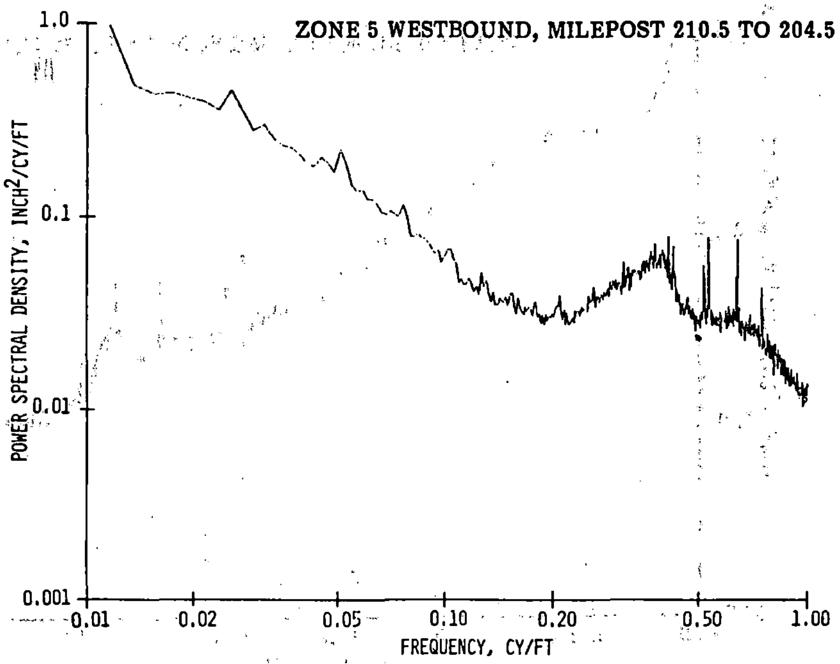


FIGURE 14. POWER SPECTRAL DENSITY - ZONE 5, GAUGE

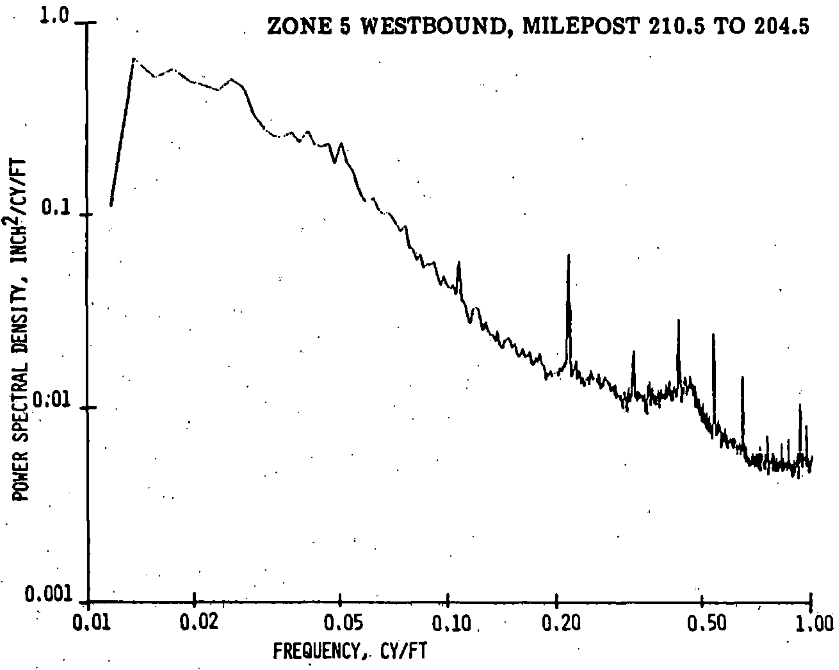


FIGURE 15. POWER SPECTRAL DENSITY - ZONE 5, AVERAGE PROFILE

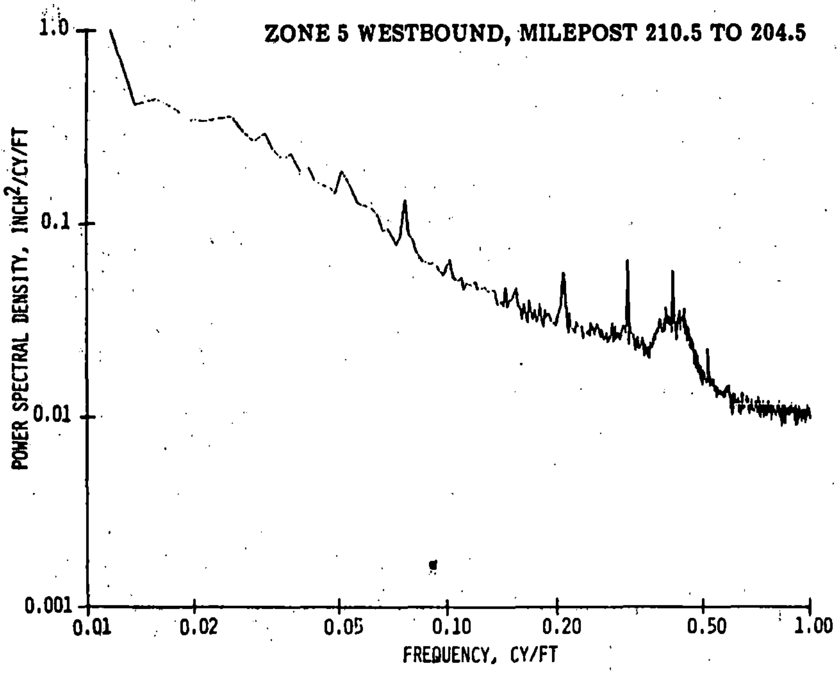


FIGURE 16. POWER SPECTRAL DENSITY - ZONE 5, CROSS LEVEL

SECTION 5
LABORATORY TEST SPECIFICATIONS

The RDL has been designed to simulate rail vehicle dynamics under laboratory conditions to discover means of reducing the costs and damages currently experienced by railroads. In addition, new vehicles can be tested to assure safety, improved ride quality, stability, and life expectancy prior to actual use.

The building of the Rail Dynamics Laboratory houses two test rigs, the Roll Dynamics Unit and the Vibration Test Unit, and supporting equipment which comprise the complete test complex. The test machines are equipped to accommodate nearly all existing and planned rail vehicles. They have special design features providing for cars varying in weight, length, wheel gauge, and axle and truck spacing. A brief description of the Roll Dynamics Unit and the Vibration Test Unit is given below.

ROLL DYNAMICS UNIT: The Roll Dynamics Unit (RDU) is used to study wheel/rail dynamic interaction. The vehicle forward motion is simulated on rollers which are controlled by drive trains consisting of a motor and one or more flywheels.

The RDU provides the capability for driving, or absorbing power from the wheelsets of a four-axle vehicle or locomotive truck. Six- or eight-axle locomotives and cars can be tested with use of auxiliary support stands. Through rotation of the rollers, the RDU simulates tangent track at various vehicle speeds and permits investigation of dynamic phenomena characteristics of "perfect" tangent track such as truck hunting. A maximum vehicle weight of 400,000 pounds can be accommodated and speeds over 144 mph can be simulated in a steady-state environment.

VIBRATION TEST UNIT: The Vibration Test Unit (VTU) is designed to study suspension characteristics of rail vehicles, component and vehicle natural frequencies, ride comfort, lading responses, component fatigue, as well as rock and roll phenomenon. The VTU provides the capability for subjecting a 320,000-pound rail vehicle equipped with two two-axle trucks or one truck of a vehicle having three or four axles, to controlled vertical and lateral vibration inputs on the wheels, creating the dynamic effects of irregular track on a vehicle. The VTU has a frequency range of 0.2 to 30 Hz and, between 0.2 and 2 Hz motions with displacements up to 2 inches can be achieved. Computer-generated rail profiles or recordings of actual rail profiles drive hydraulic actuators which can be positioned to accept a variety of truck spacings or axle arrangements.

5.1 LATERAL STABILITY

a. Data Requirements and Instrumentation

The Roll Dynamics Unit (RDU) shall be used to produce the special dynamics caused by wheel/rail interaction by simulating a vehicle's forward motion on rollers. Acceleration data shall be acquired at the following locations (see Figures 4 and 5):

- lateral accelerations at the B-end/sill level, A-end/sill level, and the center of the carbody at the sill level,
- at the B-end and A-end on the carbody at the roof level,
- at each of the axles on both trucks under the carbody.

The truck bolster yaw angle of the leading and trailing trucks shall be measured using rate gyros. The truck-mounted accelerometers shall have a range of ± 10 g's. Expected maximum ranges for purposes of scaling and calibrating are ± 10 g's for the trucks and ± 5 g's for the body. Actual measurements should be less than these.

The wheel and roller profiles shall be measured using profilometers.

The lateral accelerometers on the trucks and carbody should be recorded as well as their double integrated signals. All data channels signals shall be recorded on the analog tape and digitized and recorded on magnetic tape. Analog signals will be filtered by 20-Hz low-pass filter before being digitized.

b. Test Procedure

A continuous speed sweep shall be conducted from 30 mph to the onset of severe hunting (if it occurs without excitation). Subsequent test runs shall consist of incremental speed sweeps (5 mile per hour increments) up to the onset of truck hunting, followed by a decreasing sweep to zero speed. Due to the RDU simulation of "perfect tangent track", it may be necessary to excite the trucks in order to initiate hunting. If this is necessary, the trucks shall be perturbed laterally during tests for each incremental speed increase. Ten speeds having one mile per hour increments shall be selected over the speed range from slightly below the threshold of hunting speed to hard flange contact truck hunting. The threshold of hunting speed is the lowest speed at which sustained oscillation of hunting occurs. A rotary vibrator may be used on the carbody for purposes of overcoming static friction of truck components (Reference 9).

c. Data Reduction and Analysis

The outputs of the lateral accelerometers and angle rate gyros shall be examined using time history plots to identify the hunting phenomenon. The rms and the peak values of the collected data shall be determined and plotted as a function of vehicle speed. The damping ratios of the hunting mode will be calculated using the log decrement method. It will be plotted versus speed. The effective conicity will be calculated from wheel/roller profile data.

5.2 TRACKABILITY

5.2.1 Harmonic Roll

a. Data Requirements

The Vibration Test Unit (VTU) will be used to provide a suitable environment for the evaluation of vehicle harmonic roll response. The instrumentation transducers shall be comprised of angle rate gyros, and displacement and pressure transducers (Reference 10).

The data for roll angles and roll angle rates shall be acquired at the B-end and A-end of the carbody. The suspension deflections (across the spring group) shall be measured at both ends of the carbody. The vertical wheel loads will be obtained from measuring, for example, wheel cradle pressures with pressure transducers. The accuracy of measurements of roll angles, roll angle rates, and spring group deflections should be within 1%. The corresponding accuracy for measurement of wheel load should be within 5%. The data shall be filtered at 20 Hz using low pass filter and shall be at 200 samples per second.

b. Excitation Input

The excitation shall be input to the VTU actuators making use of the Profile Generating System (PGS). A rectified sine wave profile shall be used to simulate a 39-foot staggered joint tangent track. Appropriate time delays shall be induced between axles, depending on axle spacing for the test car. The rectified sine sweeps will be input with amplitude levels, for example, of 0.125, 0.25, 0.5, and 0.75 inch. (It should be noted here that the VTU does not allow wheel lift.)

c. Test Procedures

The test speeds shall range from 10 mph to 40 mph. Sample time of each speed (frequency) shall be the time required for ten low joints to be simulated. The speeds shall be simulated by inputting a discrete frequency sweep, data being recorded at each frequency dwell.

d. Data Reduction and Analysis

The test data shall be previewed through the use of time domain plots. The peak-to-peak values for roll angles, roll angle rates, and suspension deflections shall be extracted from the time history data, tabulated, and then plotted versus speed (frequency). The maximum and minimum values of wheel vertical loads shall be determined. By examining the time history data at different frequency dwells, the resonant speeds (frequencies) will be identified.

5.2.2 Bounce/Pitch

a. Data Requirements and Instrumentation

The Vibration Test Unit (VTU) shall be used to vibrate the rail car to simulate the action of parallel joint tangent track, and consequently examine the bounce/pitch phenomenon. Vertical acceleration data shall be acquired at, as a minimum, the B-end, A-end, and the center of the carbody at the sill level. The spring group deflections at both ends of the carbody shall be measured. The data for wheel vertical loads shall also be acquired. The accuracy of measurements for the accelerometers and the displacement transducers shall be within 1% and the accuracy for pressure transducers used to measure wheel loads shall be within 5%. The data shall be filtered at 20 Hz, using a low-pass filter and digitized at 200 samples per second.

b. Excitation Input

The Profile Generating System (PGS) shall be used to generate a rectified sine wave profile that simulates a 19½-foot parallel joint tangent track. Appropriate time delays shall be induced between axles, depending on axle spacing. The amplitude levels of the rectified sine sweeps shall be varied, for example, 0.125, 0.25, 0.5 and 0.75 inch.

c. Test Procedures

Maximum speeds ranging from 35 to 79 mph shall be simulated by inputting a discrete frequency sweep. The data acquired during the test runs shall be continuously recorded at each frequency dwell. Sample time for each speed (frequency) shall be the time required for ten low joints to be simulated.

d. Data Reduction and Analysis

The time history data for all channels shall be reviewed. The root mean square values of the vertical accelerations shall be determined and plotted versus speed (frequency). Maximum and minimum values of the vertical load at each wheel shall be determined, and the duration of wheel lift, if any, shall be identified. The bounce resonant frequency (critical speed) shall be identified from the time history plots.

5.2.3 Track Twist

a. Data Requirements and Instrumentation

Track twist load equalization includes both the static and quasi-static (very low speed) capabilities of a truck to withstand track irregularities. When the car is perfectly still, unequal wheel loads can exist, depending upon the breakout force of the friction snubbers and center of gravity location of the car. In a quasi-static case, where the rail car is traveling at a very low speed (less than 10 mph), the unequal wheel loads plus the occurrence of a lateral force can result in derailment.

A thorough investigation of load equalization shall be performed under the controlled laboratory conditions at the Rail Dynamics Laboratory (RDL). The Vibration Test Unit (VTU) shall be used to evaluate static load equalization capability. This machine allows a fully loaded car/truck configuration to be mounted on eight vertical actuators. These vertical actuators can be positioned to cross-level differences of up to about 5.9 inches between any of the four wheels of a truck.

The vertical loads at the wheel/rail interface shall be determined using, for example, pressure transducers. These values of vertical forces shall be used to calculate the wheel unloading index.

b. Test Procedure

The VTU will be used to duplicate a full range of actual track twist conditions by varying wheelset roll amplitude and roll center location. This will be accomplished by slowly and continuously varying the actuators to test all possible configurations while simultaneously recording the vertical load at each wheel.

Track twist will be set up by varying the twist amplitude and the center of rotation of wheelsets one at a time and two at a time. During the tests, data shall be recorded for both increasing and decreasing track twist in order to detect any hysteresis. It is possible to have different wheel distributions, even for the static load cases, depending upon how the friction snubbers lock up when they come to rest.

c. Data Reduction and Analysis

The measured vertical loads at the wheel/rail interface shall be used to determine the wheel unloading index. The wheel unloading index will be plotted versus the angle of twist within axle spacing of the truck.

Test data analysis shall consist of evaluating the WUI performance index for the full range of track twist and up to the maximum accommodation during laboratory testing. Identification of the worst case conditions will allow correlation with existing track geometries encountered in yards, sidings, and special track work.

5.3 RIDE QUALITY

a. Data Requirements and Instrumentation

The Vibration Test Unit (VTU) will be used to generate the test data required to characterize the ride quality regime. Lateral and vertical aceleration data shall be acquired at least at the B-end and A-end and carbody center at sill level. Lateral acceleration data shall be acquired at the B-end and the A-end on the carbody at the roof level.

The acceleration data acquired through accelerometers shall meet the following minimum criteria:

cut-off frequency: 30 Hz

range of measurements: ± 10 g's

accuracy of measurements: 1%

The wheel excitation, whether it is generated using computer or previously recorded actual rail profiles, shall be recorded continuously and simultaneously with the output response data.

b. Excitation Input

Computer-generated rail profiles making use of the Profile Generating System (PGS) or recordings of actual rail profiles shall be used to drive the hydraulic actuators. The track shall be class 4 or better. The time delay due to the axle spacing will be taken into account when exciting the vehicle system. The track geometry parameters of interest in the study of the ride quality regime are profile, alignment, gauge, and cross level.

c. Test Procedure

The test speeds shall range from 30 to 79 mph. Sample time of each speed shall be 60 seconds. The data shall be recorded continuously at each speed dwell. Each track input (profile, alignment, gauge, and cross-level) shall be treated separately, and then collectively to study the effect of coupling in the multi-degree of freedom system.

d. Data Reduction and Analysis

Detailed data analysis shall be performed on the test data. The analysis shall include calculations of the frequency content of the data (i.e., the power spectral density functions using Fast Fourier transform technique), the rms values of the output signals and the wheel input, and the percent of the time a signal amplitude is above a given level as a function of that level. The transmissibility between the output signal and the wheel excitation shall be calculated (the leading wheel of the leading truck can be used as a reference). This transmissibility may be characterized by a frequency-dependent function of amplitude ratios called a transfer function, or a sequence of root mean square (rms) ratios of output-to-input over selected frequency bands (for example 0-4 Hz, 4-10 Hz, and 10-20 Hz).

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