U.S. Department of Transportation
Federal Railroad Administration

LOCOMOTIVE CONTROL COMPARTMENT SAFETY PROGRAM: LOCOMOTIVE HEAVY AXLE LOAD TESTS

Office of Research and Development
Washington D.C. 20590

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Transportation Test Center
Pueblo, Co 81001**

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Final Report

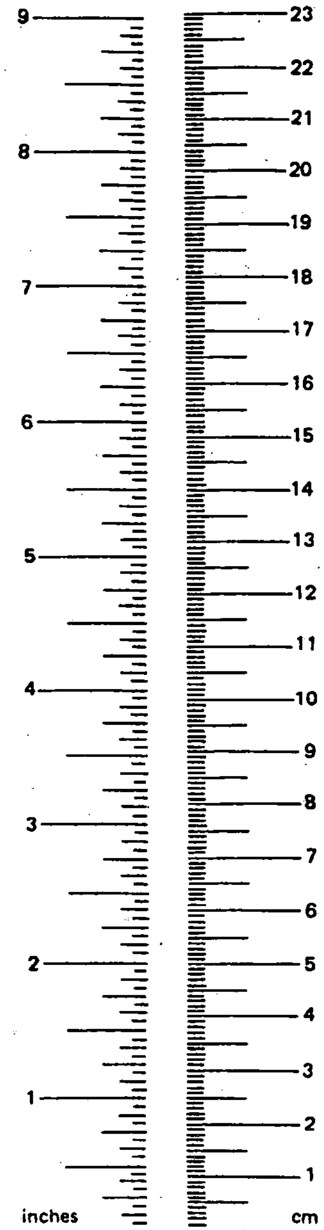
DISCLAIMER

METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

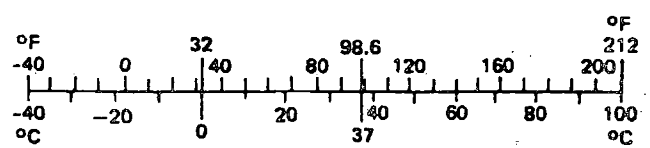
Symbol	When You Know	Multiply by	To Find	Symbol
	LENGTH			
in	inches	*2.50	centimeters	cm
ft	feet	30.00	centimeters	cm
yd	yards	0.90	meters	m
mi	miles	1.60	kilometers	km
	AREA			
in^2	square inches	6.50	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.80	square meters	m^2
mi^2	square miles	2.60	square kilometers	km^2
	acres	0.40	hectares	ha
	MASS (weight)			
oz	ounces	28.00	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.90	tonnes	t
	VOLUME			
tsp	teaspoons	5.00	milliliters	ml
Tbsp	tablespoons	15.00	milliliters	ml
fl oz	fluid ounces	30.00	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.80	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
	TEMPERATURE (exact)			
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

* 1 in. = 2.54 cm (exactly)



Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
	LENGTH			
mm	millimeters	0.04	inches	in
cm	centimeters	0.40	inches	in
m	meters	3.30	feet	ft
m	meters	1.10	yards	yd
km	kilometers	0.60	miles	mi
	AREA			
cm^2	square centim.	0.16	square inches	in^2
m^2	square meters	1.20	square yards	yd^2
km^2	square kilom.	0.40	square miles	mi^2
ha	hectares (10,000 m^2)	2.50	acres	
	MASS (weight)			
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
	VOLUME			
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.10	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	36.00	cubic feet	ft^3
m^3	cubic meters	1.30	cubic yards	yd^3
	TEMPERATURE (exact)			
°C	Celsius° temperature	9/5 (then add 32	Fahrenheit temperature	°F



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16. Abstract

The Federal Railroad Administration sponsored a program to evaluate the wheel on rail dynamic safety performance of locomotives with increased cab weight at the Transportation Test Center, Pueblo, Colorado. The increased weight represents the weight of a cab reinforced to protect the occupants in the case of an accident. The program consisted of on-track tests to evaluate the safety performance, and assembly and validation of a mathematical model of the locomotive to be used to extend the scope of the track tests.

Tests were performed to measure the suspension characteristics of a locomotive. This data was used as input to a mathematical model that could be used to simulate the locomotive under a wide range of track conditions. The model was verified by comparison with the results of the on-track tests.

On-track tests subjected the locomotive to normal and increased weight configurations in most of the AAR Chapter XI dynamic performance tests. The results of these tests were used to evaluate the safety performance of the increased weight locomotive.

Test results showed that the increased weight caused no noticeable change in the dynamic safety performance of the locomotive. The comparisons of the test results with the model predictions indicated a need to improve the model in one area before it would be completely verified. The model did however confirm that the performance of the locomotive is unaffected by the increased cab weight. When the model is completely verified, it can be used to evaluate locomotive performance for a wide range of cab weight configurations and different track conditions.

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EXECUTIVE SUMMARY

The Federal Railroad Administration (FRA) sponsored a research program at the Transportation Test Center, Pueblo, Colorado, to investigate the effects of increased locomotive cab weight on the wheel-on-rail dynamic performance of locomotives. The Locomotive Control Compartment Committee (LCCC) had investigated improvements to the locomotive cab structure that would increase the safety of the cab occupants in the event of an accident. These improvements could lead to increases in cab weight of up to 10,000 pounds.

The research methods used were based on methods successfully devised and implemented under past jointly funded FRA and Association of American Railroad (AAR) research programs. These methods involved on-track tests to determine basic vehicle safety performance, combined with development and verification of a computer model of the test vehicle to allow more extensive analysis of the vehicle's safety performance. The general methodology involved:

- Conduct laboratory tests to measure the locomotive's suspension and car body characteristics.
- Use the measured characteristics in a mathematical model to predict the dynamic behavior of the locomotive.
- Perform on track tests of the locomotive to measure dynamic safety performance, with the locomotive in normal configuration and in two increased cab weight configurations.
- Compare predicted performance with test results, to verify the mathematical model. Once verified, the model can be used to extend the scope of the analyses to loads and track conditions not tested.

The on-track tests and model analyses were based on the requirements of Chapter XI of M-1001 in AAR's *Manual of Standards and Recommended Practices*. The mathematical model used was the NUCARS* general vehicle dynamics model developed by the AAR.

The results of both the NUCARS modeling and the track tests indicate that the dynamic performance of both increased load configurations was virtually the same as for the normal weight unmodified locomotive. The two increased load configurations tested were (1) 20,000 pounds

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* New and Untried Car Analytic Regime Simulation

added to the cab end and (2) 20,000 pounds added to the cab end and an increase in the stiffness of the primary coil springs, as recommended by the locomotive manufacturer for the increased axle load. The increased loads were obtained by stacking lead bricks around the periphery of the cab, to simulate the approximate load distribution that a crash structure would add to a locomotive.

For most of the Chapter XI type test conditions, the dynamic performance was well within Chapter XI performance criteria. For the few cases where performance was near or above the recommended Chapter XI limiting criteria, all three configurations showed similar performance. In most instances, it appeared that the amount by which the Chapter XI criteria were exceeded was within the measurement accuracy of the instrumented wheel sets used to measure the wheel-on-rail forces. The Chapter XI criteria were exceeded in the limiting spiral exit and the dynamic curve. In the 10-degree curve, Chapter XI criteria were also exceeded but the data appears anomalous when compared to the results in the 7.5- and 12-degree curves.

The mathematical model was successfully assembled from the laboratory test measurements of the locomotive suspension and modal parameters. However, the model predictions when compared with the test results indicated a problem with the simulation of the secondary vertical leaf spring suspension. It appeared that in the model the leaf spring friction was "locking up" preventing an accurate simulation. This caused a poor match between the model predictions and the test results. In particular the bounce tests, and the twist and roll tests showed much lower resonant speeds than the model predictions. As already noted, the predictions for the three load configurations were similar, supporting the conclusion that the added weight in the cab has little effect on locomotive safety performance.

It is recommended that a follow up project be established to rectify the problem with the leaf spring model and complete verification of the model predictions with respect to the test data. The locomotive model can then be used to extend the range of the analyses to loads and track configurations not tested. In addition the test data already collected should be analyzed to determine whether the increased cab loads could impart increased maximum loads to the tracks. These loads would not cause immediate safety concerns but could cause increased track deterioration and wear.

The track tests pointed out some deficiencies with the available instrumented wheel sets required for performing on-track dynamic tests of locomotives. It is recommended that for future on-track dynamic tests new instrumented wheel sets be obtained that utilize the latest techniques in wheel-on-rail force measurement. The tests were performed using instrumented wheel sets leased from the locomotive manufacturer. These proved acceptable and reliable, although a few documented flaws limit the ultimate accuracy of the test results. In all cases, the tests data was processed to account for these flaws to view the results conservatively.

Recent developments in instrumented wheel set design by the AAR offer the potential for much more accurate and reliable equipment than was used for this test. Future research programs should take advantage of this new technology.

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1.0 INTRODUCTION

The Federal Railroad Administration (FRA) and the Locomotive Control Compartment Committee (LCCC) are investigating the feasibility of improved designs for locomotive control compartments. These improvements are intended to enhance the safety of the locomotive cab occupants in the event of a collision or other accident. Various new designs of reinforced cab have been developed as a result of these investigations. These cabs are expected to weigh 6,000 to 10,000 pounds more than a conventional cab. When installed on a 4-axle locomotive this would increase the axle loads above the currently acceptable 33-ton axle load limit. The Locomotive Heavy Axle Load Program was carried out at the Transportation Test Center (TTC), Pueblo, Colorado, to investigate the effects of the increased axle loads on the dynamic wheel-on-rail performance of 4-axle locomotives.

The project has combined the techniques of on-track testing and mathematical simulation to evaluate the dynamic performance of a typical 4-axle locomotive under three different load configurations. The mathematical model used is the New and Untried Cars Analytic Regime Simulation (NUCARS) computer model developed by the Association of American Railroads (AAR).

The NUCARS model of the locomotive was to be refined and verified by comparison with the on-track results. Initial comparisons showed discrepancies between test results and model predictions due to a problem modeling the vertical leaf spring friction. Once this problem is rectified and the verification process is completed, the model can be used for evaluating track conditions and locomotive suspension and cab configurations not tested.

The tests and dynamic analyses were similar to those successfully implemented for the FRA under other programs.[1,2,3] These were based on the dynamic tests and analyses required for the evaluation of new freight cars as specified in the AAR's *Manual of Standards and Recommended Practices,* Chapter XI.

2.0 OBJECTIVES

The project had the following two objectives:

1. To measure and compare the dynamic performance of locomotives with normal (33-ton) and increased axle loads, by means of on-track tests
2. To simulate the on-track tests using a computer model which, when validated, can be used to predict the dynamic performance over a broader range of track conditions

3.0 PROJECT METHOD

As stated, the project method is based on the successful vehicle test and analysis methods developed under past FRA programs. These programs evaluated the dynamic performance of two new design freight cars through a combination of laboratory tests, mathematical modeling, and on-track testing. The methods used were based on the AAR's Chapter XI tests and analyses.

For this project, the tests and analyses were performed on a locomotive in a normal load configuration and two modified configurations with heavier axle loadings and heavier duty suspensions. The program consisted of the following procedures.

1. VEHICLE CHARACTERIZATION TESTS: These tests were performed to provide input data for the NUCARS model. The locomotive suspension characteristics and car body rigid and flexible body modal characteristics were measured. Most tests were conducted on the Mini Shaker Unit (MSU) test facility.

2. NUCARS MODELING: This procedure was performed to develop NUCARS computer models of the three vehicle configurations, using the measured vehicle characteristics. The NUCARS models were to be verified by simulating the on-track tests. Once the models are verified they can be used to extend the range of the track tests to simulate other vehicle configurations and track conditions.

3. ON-TRACK TESTS: These tests were performed to measure the on-track dynamic performance of the three different locomotive configurations and provide data for verifying the NUCARS computer models. The on-track tests were similar to the ones used in the FRA Light Weight Car research programs. These were based on the AAR's Chapter XI vehicle acceptance tests and include tests on curved and tangent tracks with perturbations. Dynamic performance analyses were based on wheel-on-rail interaction forces measured with instrumented wheel sets.

4.0 TEST VEHICLE

The intent of the test program was to make use of a test vehicle that was representative of relatively modern 4-axle locomotives. It was therefore decided that an EMD, GP type locomotive, with the "Dash 2" type of suspension upgrades, would be the most suitable type to test. This reasonably represents a significant portion of the locomotive fleet currently in operation. The suspension upgrades for this locomotive are representative of what would be normally ordered on new and rebuilt locomotives.

Considerable effort was expended trying to locate such a locomotive that could be loaned by a railroad to the FRA for the duration of the test program. Unfortunately, because this type of locomotive represents the core of most railroads' fleets, none could be spared for the time period required.

While searching for alternatives, it was realized that the test locomotive did not actually have to be operable, but merely have a suitable weight and suspension. Therefore it was decided to modify a scrap GP-35 locomotive available at the TTC to include the required suspension upgrades. One of the TTC's GP-40 locomotives had a spare set of trucks that had been previously upgraded to Dash 2 specifications for use in high speed tests. The Dash 2 suspension upgrades include:

- Low profile secondary leaf springs to provide clearance for a single brake shoe per wheel braking system
- Vertical hydraulic dampers between the axle and truck frame, one per axle at diagonally opposite corners of the truck
- A lateral hydraulic damper between the truck bolster and spring plank to control lateral oscillations of the secondary swing link suspension

The upgraded trucks were installed under the scrap locomotive. The trucks also included some additional yaw suspension dampers to control high speed oscillations. These are not normally included on freight locomotives but are a common addition to modern high speed passenger locomotives. The dampers were left in place for these tests because it was believed they would not significantly affect the low speed tests being performed.

Figure 1 shows a general view of the test vehicle with the upgraded trucks installed. Figures 2 and 3 are close up views of an upgraded truck, showing the details of the vertical axle dampers, lateral bolster damper, and yaw dampers between car body and truck frame.

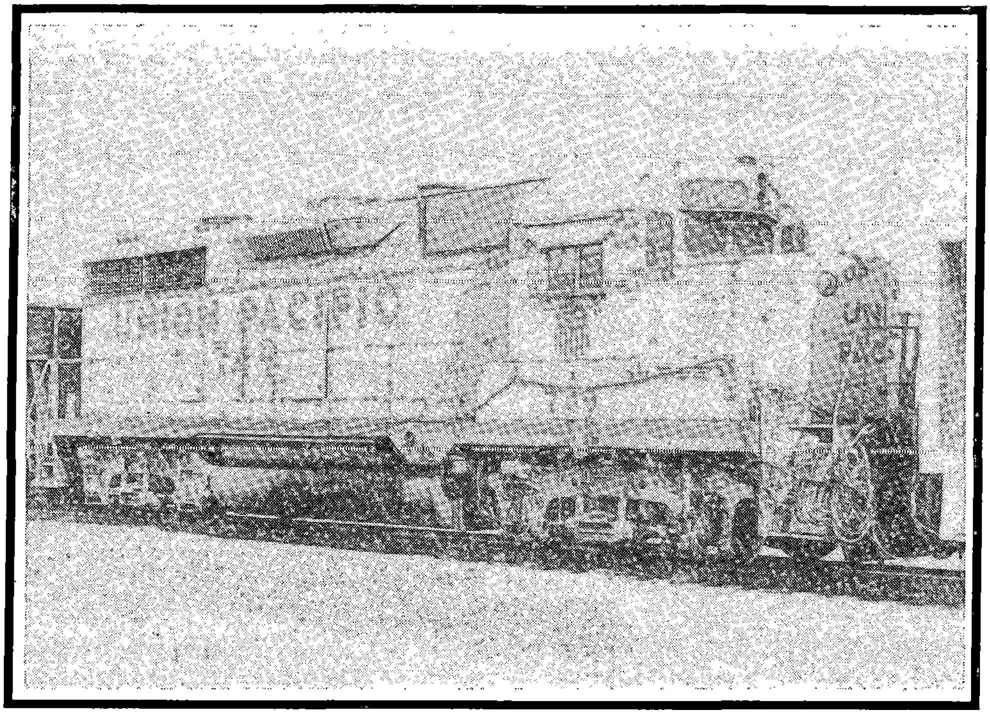

Figure 1. GP-35 Test Locomotive With Upgraded Trucks

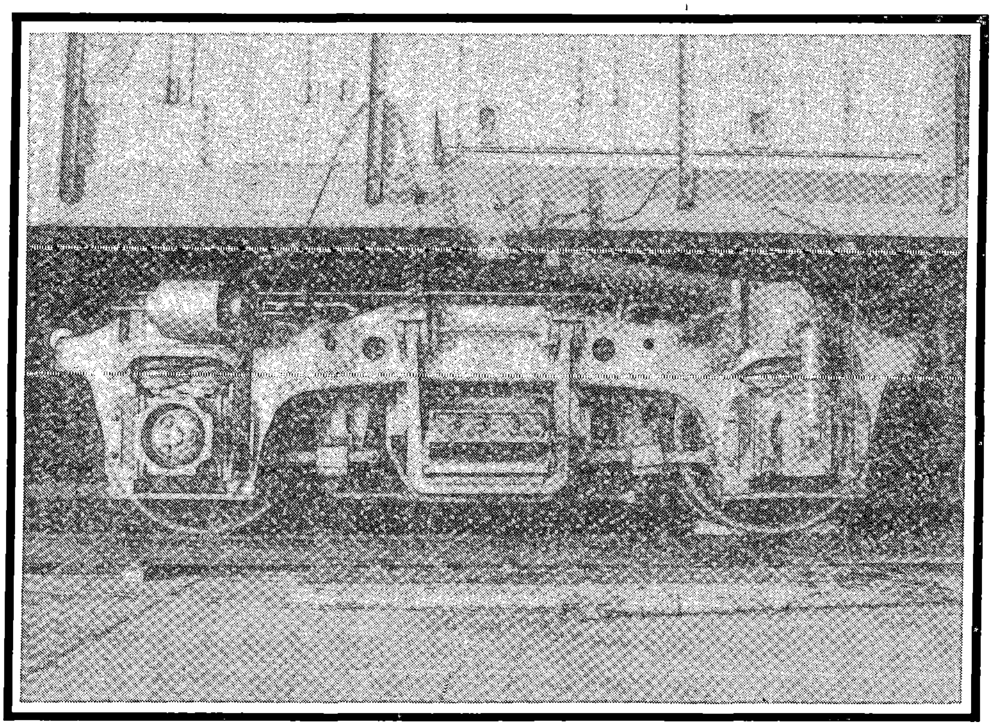

Figure 2. Upgraded Locomotive Trucks Showing Vertical and Yaw Dampers

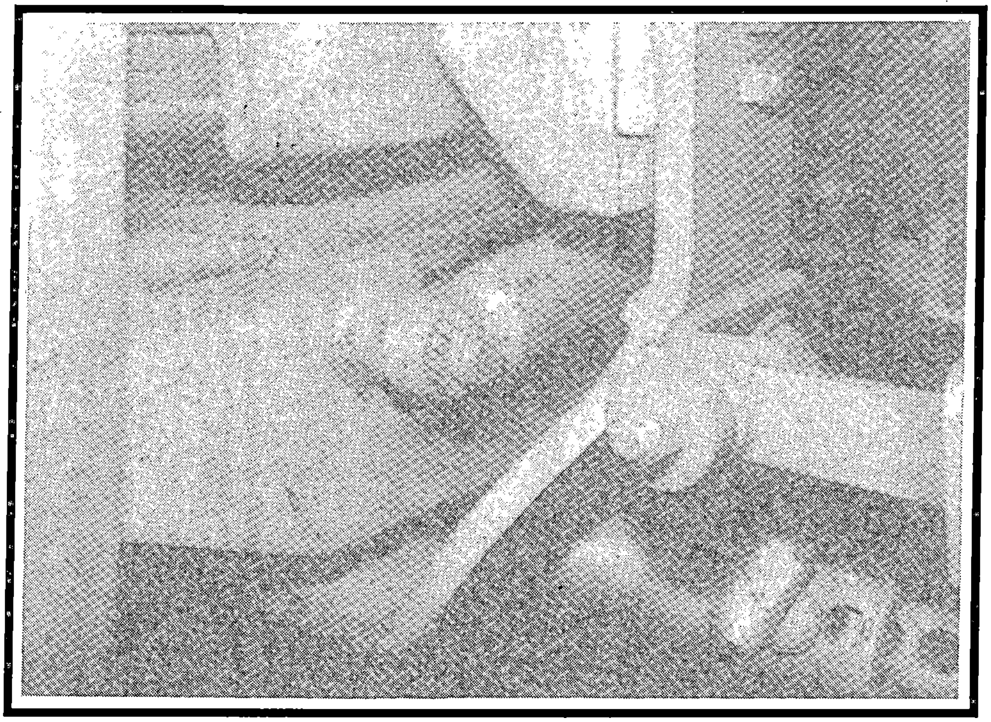

Figure 3. Detailed View of Lateral Damper Connecting the Spring Plank (Truck Bolster) to the Truck Frame

The locomotive was tested and modeled in the three following configurations:

1. Normal load with the springs as originally installed.
2. Load increased at the cab end with 20,000 pounds of lead bricks to represent the additional weight of a crash resistant structure.
3. Load increased at the cab end with 20,000 pounds of lead, with stiffer primary coil springs installed as recommended by the manufacturer to support the increased load.

The lead load was placed inside the locomotive cab in two stacks along the outside walls. This was to get the center of gravity (C.G.) as high as possible and as far out to the sides as possible to best represent the probable C.G. location and increased roll moment of inertia of a reinforced cab structure.

5.0 VEHICLE CHARACTERIZATION TESTS

Vehicle characterization tests were conducted in three separate phases. To measure the vertical, lateral, and roll suspension characteristics, and the rigid and flexible car body suspension characteristics of the whole vehicle in configuration 1, dynamic tests were conducted using the MSU test facility. To measure the yaw suspension characteristics and the axle alignments, quasi-static tests were performed on air tables. Additional tests were performed in a load frame to measure the stiffness of the upgraded springs used in configuration 3 and to accurately measure the damping characteristics of the various hydraulic dampers.

5.1 DYNAMIC VEHICLE CHARACTERIZATION TESTS USING THE MSU

The MSU was developed to perform dynamic measurements of vehicle suspension and modal characteristics. It consists of two vertical and one lateral hydraulic actuator to excite one end of a test vehicle over a wide range of frequencies and displacements. The test vehicle is supported on a set of rails instrumented to measure the vertical and lateral forces. A complete description of the MSU is included in FRA report "Safety Aspects of New and Untried Freight Cars.[1]

The MSU is operated in two modes. The first mode is at low frequency (0.1 Hz to 0.2 Hz) to measure the suspension stiffness and damping characteristics without the influence of the car body and suspension components' inertial forces. The second mode is to perform modal tests by sweeping frequency from 0 to 20 Hz to measure the rigid and flexible body modal parameters.

The MSU configuration allows measurement of the vertical, lateral, and roll suspension characteristics. Modal measurements possible are vertical, lateral, and torsional bending of the locomotive body and the vertical, lateral, and roll resonant frequencies of the suspension.

5.1.1 Test Procedures

The locomotive was placed in the MSU as shown in Figure 4, with cab end being characterized. Tests were performed with the locomotive in configuration 1 (normal load, normal suspension). Tests were performed in two stages, first with the hydraulic dampers disconnected, then repeated with the dampers reconnected. This was done to allow better identification of the effects of the dampers on vehicle performance.

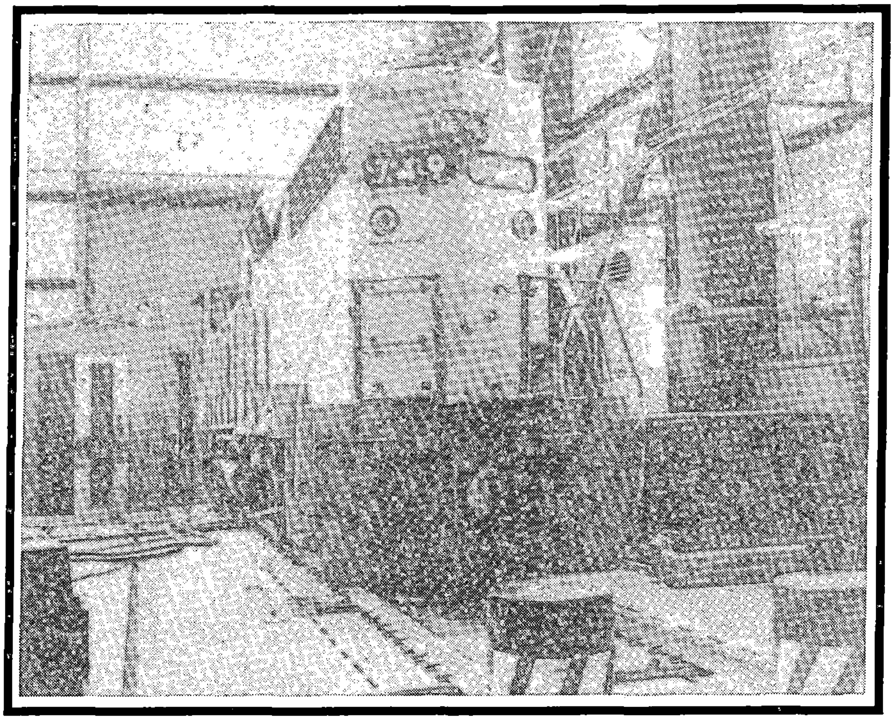

Figure 4. Locomotive in MSU for Vehicle Characterization Tests

Test measurements included vertical and lateral rail forces, hydraulic actuator forces and deflections, suspension deflections, and car body accelerations. Appendix A lists the instrumentation used. Test data was collected using the TTC's Hewlett-Packard (HP) desk top computer based system. Data was stored on digital media for later analysis.

Suspension characteristic testing consisted of exciting the locomotive at low frequency vertically, laterally, and in roll, each in turn, and measuring the suspension deflections and induced loads. Modal tests were conducted similarly using frequency sweeps, and measuring the accelerations of the body in a number of locations for later modal analysis.

5.1.2 Test Results

Suspension characteristic data was analyzed by plotting suspension deflections against the applied loads for the given suspension component. Damper characteristics were estimated from the hysteresis shown in the resulting force deflection plots and by calculating the suspension velocities and plotting them against the applied loads. A typical force/deflection plot for the secondary vertical leaf spring suspension is shown in Figure 5. This shows a very complex hysteretic damping characteristic due to the friction between the spring leaves.

Table 1 summarizes the measured suspension characteristics.

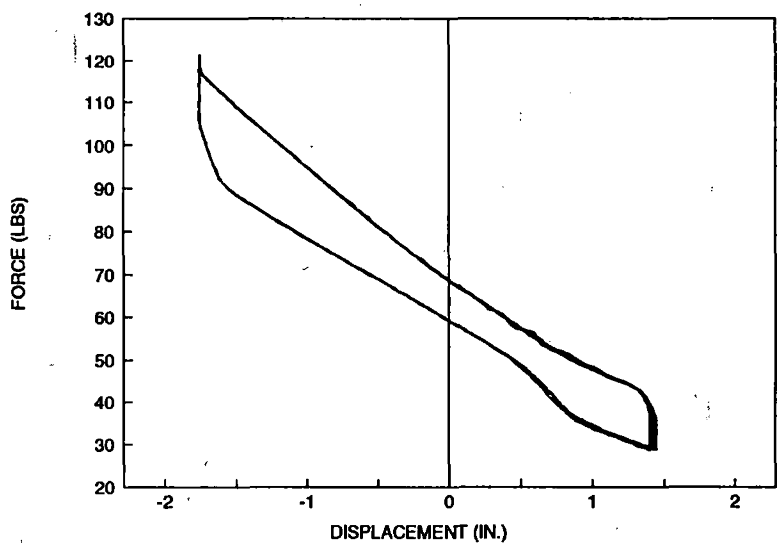

Figure 5. Measured Force vs Displacement Hysteresis Loop Characteristics for the Left Side Secondary Vertical Leaf Spring

Table 1. Measured Locomotive Suspension Characteristics

SUSPENSION CHARACTERISTIC	STIFFNESS	DAMPING
Soft Vertical Primary Coil Springs (Configs. 1 & 2)	8,200 lb/in 5.5 inch travel	65.5 lb friction
Stiff Vertical Primary Coil Springs (Config. 3)	9,410 lb/in 5.5 inch travel	65.5 lb friction
Vertical Secondary Leaf Springs	24,000 lb/in*	7,500 lb* Hysteretic Friction
Lateral Primary Coil Springs	1,200 and 12,500 lb/in two stage 0.2 inch clearance	1,200 lb friction
Lateral Secondary Swing Links	7000 lb/in 4 inch travel	9,080 lb friction
Truck Yaw Rotation	None	5,770 lb-in friction
Vertical Damper	Bushing Stiffness: 3,700 lb/in	530 lb/in/sec
Lateral Damper	Bushing Stiffness: 7,940 lb/in	400 lb/in/sec
Yaw Damper	Bushing Stiffness: 15,240 lb/in	5,340 lb/in/sec, 76 lb/in/sec blowoff above 0.47 in/sec
Traction Motor Rubber Mount	17,500 lb/in	100 lb/in

*The data for the secondary vertical leaf spring are average values for the entire travel of the spring. The characteristic shows a large amount of hysteretic friction damping, creating a very complex force/displacement envelope. The characteristic data input to the NUCARS model uses the entire hysteretic damping envelope and not these average values.

The modal characteristics were calculated by performing an analysis of the measured car body accelerations and input forces and deflections using Structural Measurement Systems (SMS) Modal 3.0 software. Mode shapes were identified and the modal frequencies and damping ratios estimated. Table 2 summarizes the results of the modal analysis.

Table 2. Measured Locomotive Modal Parameters

VIBRATION MODE	MODAL FREQUENCY	MODAL DAMPING RATIO
Bounce	1.6 Hz	*
Pitch	2.3 Hz	*
Lower Center Roll	0.5 Hz	*
Upper Center Roll	2.4 Hz	*
Body Twist	5.5 Hz	0.013
Vertical Bending	6.3 Hz	0.047
Lateral Bending	30.0 Hz*	0.02*

*Modal damping ratios were not estimated for the rigid body suspension modes. The lateral bending mode was indistinct and was apparent only at the highest test frequencies of 30 Hz.

5.2 QUASI-STATIC (AIR BEARING) TESTS

5.2.1 Truck Rotation Tests

Due to its design, the MSU is not capable of measuring any suspension characteristics involving yaw motions. In the case of a locomotive, the yaw rotation characteristic of the truck relative to the car body needs to be determined. Therefore these tests are performed by supporting the locomotive on air tables and rotating the truck relative to the body, with the air table providing a frictionless bearing between the truck and the ground.

The cab end truck was lifted on air tables as shown in Figure 6. Hand operated hydraulic actuators were connected between diagonally opposite corners of the table and restraints fastened to the ground. The rotation of the truck was measured using string potentiometers connected between the truck frame and the locomotive body. Load cells attached to the actuators measured the rotational forces. Rotational moments were calculated from the applied actuator loads and plotted against the rotational angles. See Table 1 for a summary of these results.

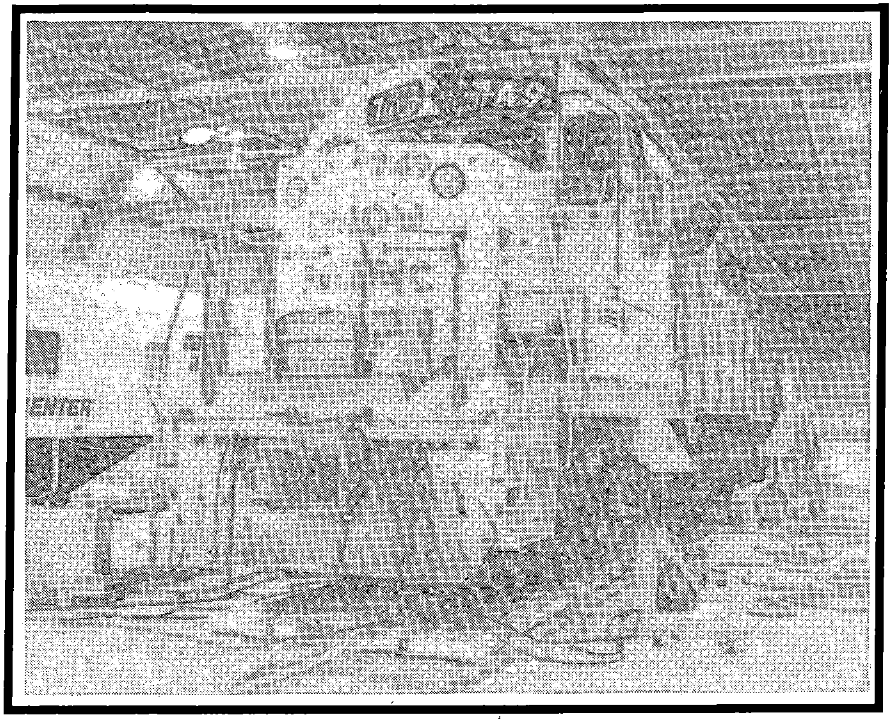

Figure 6. Locomotive Mounted on Air Tables, with Hydraulic Actuator Attached for Truck Rotation Tests

5.2.2 Axle Alignment Tests

An additional test, performed on air tables, is the measurement of the axle alignment. This is an important parameter which can significantly affect the curving behavior of a vehicle. To perform these tests each axle of the locomotive lead truck was supported by a separate air table. This allowed each axle to move freely relative to each other and the truck frame. The alignment of each axle relative to the truck frame was then measured with a surveying instrument. The results of these tests showed no axle misalignment.

5.3 INDIVIDUAL COMPONENT TESTS

Several suspension components were individually tested in a load frame to measure their characteristics. These included the hydraulic dampers, the stiffer primary suspension coil springs used in the configuration 3 tests, and the rubber blocks used to suspend the locomotive traction motors on the truck frames. The individual suspension components were mounted into the load frame and the load frame cycled to measure the force and deflection characteristics of each component throughout its range of motion. Measured data included the applied loads and the load frame displacements and velocities. Data was recorded graphically by an x-y plotter and suspension characteristics determined from the resulting plots.

Figure 7 shows testing of a hydraulic damper in progress. In the case of the hydraulic dampers, the deflection of the rubber mountings was measured in addition to the built-in load frame measurements. By cycling the load frame at different frequencies, the force displacement and force velocity characteristics of both the dampers and the rubber bushings were obtained. See Table 1 for the results of these component tests.

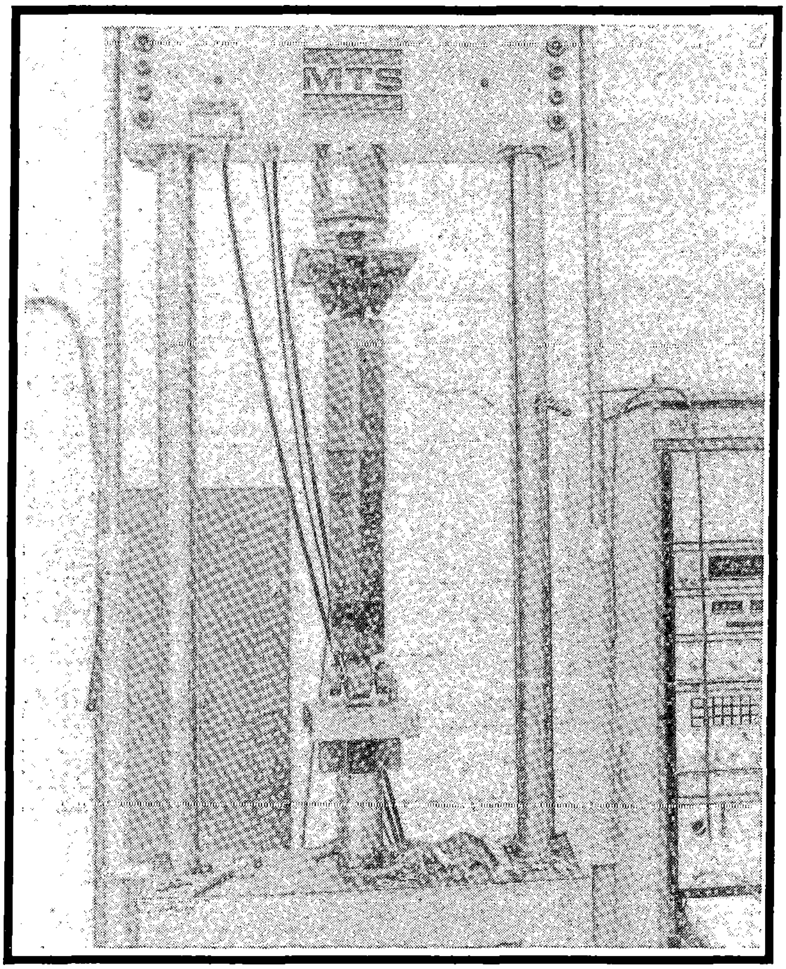

Figure 7. Vertical Hydraulic Damper Being Tested in Hydraulic Load Frame

6.0 PROCEDURES FOR TRACK TESTS AND NUCARS MODEL PREDICTIONS

The track tests and NUCARS model simulations followed the methods used for performing Chapter XI tests, as perfected during previous FRA research programs. Testing was performed over all Chapter XI test zones in place at the TTC except that no high speed lateral stability (hunting) tests were performed. This is because past experience has shown that locomotives do not exhibit high speed stability problems until well above the 70 mph maximum test speed. The entire test and modeling sequence was repeated for each of the three load and suspension configurations. The tests performed were as follows:

- Pitch and Bounce
- Twist and Roll
- Yaw and Sway
- Curve Entry/Exit
- Steady State Curving
- Dynamic Curving

6.1 TEST CONSIST

The original intent of the test program was to have the test locomotive provide propulsion for the test train. Because the test locomotive turned out to be a nonfunctioning scrap unit, a separate operating locomotive was used to pull the test consist. An instrumentation coach was connected between the power locomotive and the test locomotive, as shown in Figure 8. The instrumentation coach contained all the signal conditioning, data collection computers, and test personnel.

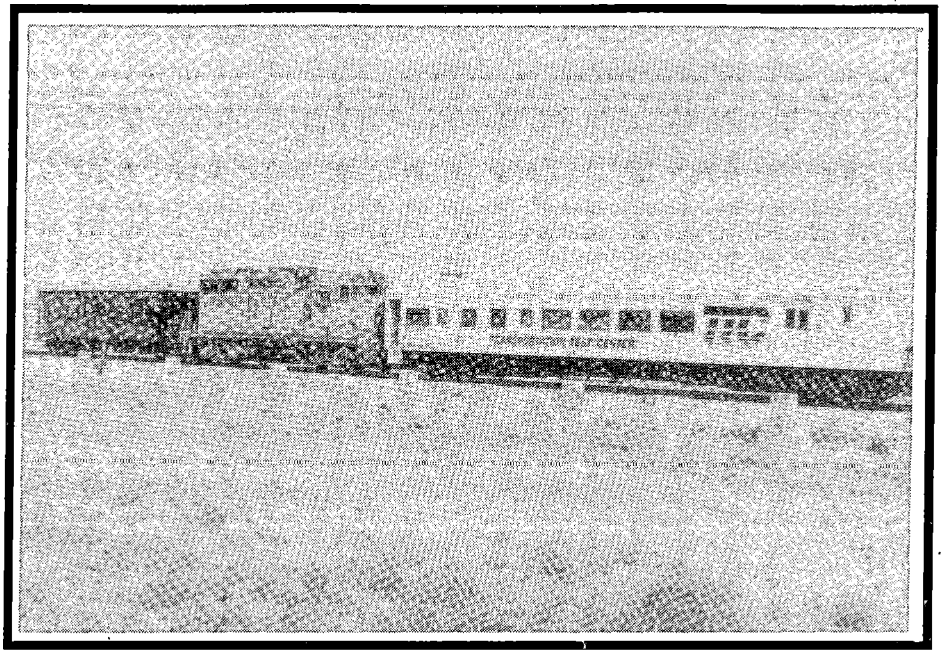

Figure 8. Test Consist for the On-Track Tests

6.2 INSTRUMENTATION

The instrumentation for the tests was based upon two instrumented wheel sets mounted in the cab end truck to measure the instantaneous vertical and lateral wheel forces. Additional instrumentation consisted mostly of displacement transducers mounted to measure the deflections of various suspension components. Roll gyrometers and accelerometers were also installed to measure the locomotive body roll behavior and lateral accelerations. Most of the suspension deflection data was measured for comparison with the NUCARS model predictions to assist in the verification of the model.

All measured data was filtered at 15.0 Hz, digitized and stored on digital media for later analysis using one of the TTC's HP 3000 desk top computer based data collection systems. Appendix B lists all measured data channels and their locations on the locomotive.

6.2.1 Instrumented Wheel Sets

The original plan for the project called for using two instrumented wheel sets belonging to the FRA, manufactured by ASEA of Sweden in the mid-1970's. There were doubts as to their reliability and accuracy due to age and old design. The known design flaws included a lack of compensation for centrifugal forces and temperature changes. In addition, the effects of cross talk between the vertical and lateral signals and the effects of changing the lateral position on the tread of the vertical load application were unquantified. Therefore, these wheel sets were installed under the locomotive prior to the MSU vehicle characterization tests, and their performance was checked.

It was immediately obvious that something was wrong with the strain gage circuits on one of the two wheel sets, and some questionable data was being produced by the other. Both wheel sets were removed from the locomotive and were disassembled for inspection. The inspection revealed that the faulty wheel set had oil contamination under a large number of strain gages. Both wheel sets appeared to require some replacement wiring.

A further problem with these wheel sets was also discovered. The strain gages on these wheel sets had been installed with an adhesive which has a working life of about 3 years. After this, it begins to deteriorate. This will cause unknown changes to the calibration of the wheel sets, and ultimately the gages may fall off. This appears to be occurring due to the oil contamination on one wheel set.

Due to the expense of repair, the wheel sets' age, and the known shortcomings of their design, an alternative source of instrumented wheel sets was sought that could provide greater reliability and accuracy at a similar or lower cost than repairing the existing wheel sets. Ultimately, two instrumented wheel sets were leased from EMD. These were known to have an improved design without the errors associated with rotational speed or temperature fluctuations. In addition, the cross talk errors between the vertical and lateral force signals and the effect of the lateral position of the vertical load application had been quantified; although, the method for handling these errors was relatively crude.

The method for handling the errors involved calibrating the vertical strain circuits with the vertical load applied at three different positions across the wheel tread. Three different sets of calibration constants were calculated, one for flange contact, one for the middle of the tread, and one for the field side of the tread. The calibration constant used is dependent on the lateral position at which the wheel is believed to be running. This method works best for the constant curving runs when the wheel position is relatively constant. However for cases where wheels are moving laterally throughout the test zone, such as curve entry, yaw and sway, and dynamic curving, the method is flawed. Therefore it was decided to use the calibration constant that would result in calculating the smallest vertical forces. This would ensure always producing the largest lateral to vertical (L/V) force ratios, resulting in conservative estimates of vehicle safety performance. This turns out to be the calibration constant for the lateral position when the wheel is in flange contact.

Some of the discrepancies between the test results and model predictions may be due to the possibility of underestimating the vertical wheel loads and hence overestimating the L/V ratios by these methods. This is most likely to occur for a nonflanging wheel.

Although the EMD instrumented wheel sets are an advance in technology when compared to the FRA/ASEA wheel sets, the position problem presents a drawback when trying to interpret test results. Recent developments in wheel set design technology have resulted in designs that compensate for the lateral position of the vertical load application.[4]

6.3 TEST DATA ANALYSIS

All instrumented wheel set test data was analyzed post test and compared to AAR's Chapter XI recommended criteria. Although these criteria were developed for the evaluation of the safe performance of new freight cars, they represent conservative measures of safety performance. These are based mostly on the measurement of parameters that relate to derailment and are therefore directly applicable to the measurement of the safety performance of any railroad vehicle. Five basic safety criteria have been applied for these locomotive tests:

- **Minimum Percent Wheel Load:** The ratio of the instantaneous vertical wheel load to the normal static wheel load expressed as a percentage.
- **Maximum Wheel L/V Ratio:** The ratio of the instantaneous lateral force to vertical force on a wheel.
- **Maximum Axle Sum L/V Ratio:** The sum of the absolute values of the instantaneous wheel L/V ratios on an axle.
- **Maximum Truck Side L/V Ratio:** The ratio of the sum of the lateral wheel forces on all wheels on one side of a truck to the sum of the vertical forces on the same wheels.
- **Maximum Peak-to-Peak Car Body Roll Angle:** The maximum peak-to-peak roll angle between two successive roll oscillations of the car body.

Table 3 summarizes the current recommended limits for the Chapter XI performance criteria for various test regimes.

Table 3. AAR Chapter XI Criteria for Assessing the Requirements for Field Service

REGIME	SECTION	CRITERION	LIMITING VALUE
Hunting (empty)	11.5.2	minimum critical speed (mph)	70
		maximum lateral acceleration (g)	1.0
		maximum sum L/V axle	1.4*
Constant curving (empty & loaded)	11.5.3	maximum wheel L/V	1.0
		or maximum sum L/V axle	1.4
Spiral (empty & loaded)	11.5.4	minimum vertical load (percent)	10**
		maximum wheel L/V	1.0*
		or	
		maximum sum L/V axle	1.4*
Twist, Roll (empty & loaded)	11.6.2	maximum roll (deg) ***	6
		maximum sum L/V axle	1.4
		minimum vertical load (percent)	10 **
Pitch, Bounce (loaded)	11.6.3	minimum vertical load (percent)	10**
Yaw, Sway (loaded)	11.6.4	maximum L/V truck side	0.6*
		maximum sum L/V axle	1.4*
Dynamic curving (loaded)	11.6.5	maximum wheel L/V	1.0 *
		or maximum sum L/V axle	1.4 *
		maximum roll (deg) ***	6
		minimum vertical load (percent)	10 **
Vertical curve	11.7.2	To Be Determined	
Horizontal curve	11.7.3	To Be Determined	

* Not to exceed indicated value for a period greater than 50 milliseconds per exceedence
** Not to fall below indicated value for a period greater than 50 milliseconds per exceedence
*** Peak-to-peak

The analysis process consisted of calculating the required minimum vertical wheel forces, L/V ratios, and roll angles from the recorded wheel force and roll angle data, and tabulating the required maxima and minima. Data was plotted versus speed in each test zone and compared to the same criteria predicted by the NUCARS computer model.

6.4 NUCARS MODELING

The NUCARS computer model[5] was used for simulating the performance of the three locomotive configurations operating over all test zones. It is a time domain model that allows the simulation of virtually any railroad vehicle running on most types of railroad tracks. Simulation of a given vehicle is accomplished by describing the vehicle as an assemblage of point masses connected together by a variety of suspensions. Each suspension is described as a combination of stiffness and damping characteristics. Wheel-on-rail interaction is simulated with a full, nonlinear calculation of the creepages between the wheels and rails.

Input files describing the three different locomotive configurations were assembled using the characteristics measured in the vehicle characterization tests (Section 5). Copies of these input "system" files are included in Appendix C. Additional input files describing each of the track test zones were assembled using survey measurements of the actual perturbation geometries.

Measurements were made of the profile shapes of each instrumented wheel set and were averaged together to develop an average wheel profile for the locomotive. The rail profiles were measured in each test zone and the average locomotive wheel profile was fitted to each rail profile to develop individual wheel/rail profile geometries for each test zone.

Simulations of the locomotive running in each of three configurations were made for each test zone. Simulations covered the entire range of speeds tested.

NUCARS results included lateral and vertical forces and L/V ratios on all wheels, suspension deflections, and car body motions. These were tabulated in a similar manner to the on-track test data for easy comparison.

7.0 TEST AND MODEL RESULTS

7.1 PITCH AND BOUNCE

The pitch and bounce test zone consists of tangent track with segments of rail 39 feet long. The middle of each segment is raised 3/4 inch creating simulated low joints at each segment end. The low joints on each rail coincide with each other, as illustrated in Figure 9.

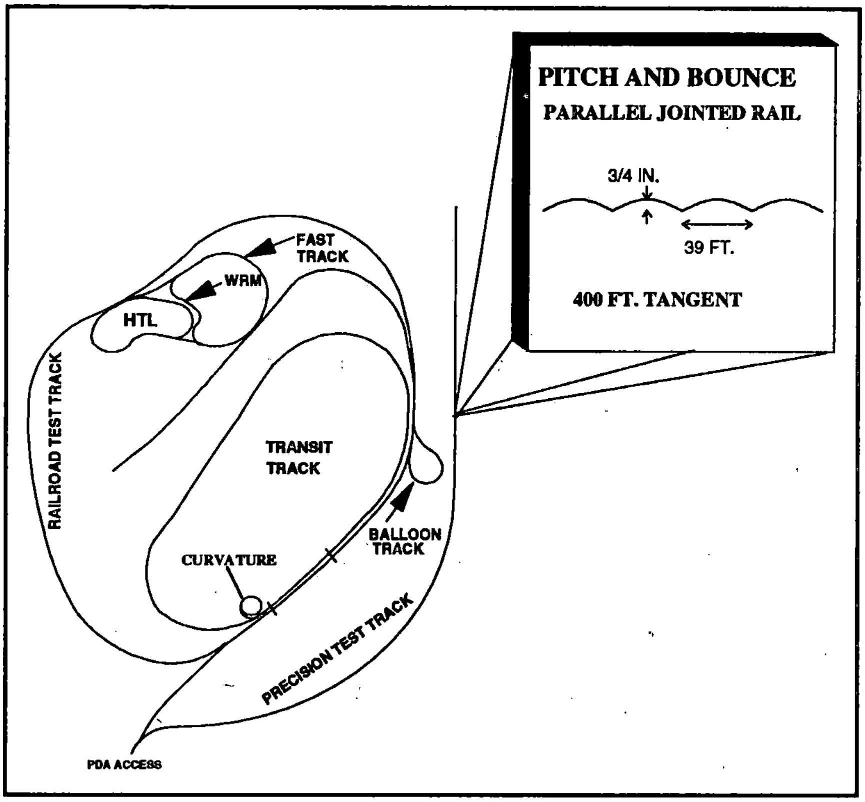

Figure 9. Pitch and Bounce Test Zone at TTC

Predicted and measured minimum percent wheel loads for the three configurations are compared in Figures 10 through 13. Test data and model predictions show good performance for all three configurations with the lowest wheel loads of 60 percent of the static load being measured for the normal load (configuration 1) at 33 mph. This is well above the Chapter XI minimum of 10 percent. The increased load in configurations 2 and 3 shifts the resonant speed to near 40 mph. The change to stiffer springs in configuration 3 appears to have little effect on the measured minimum loads or resonant speed when compared to configuration 2.

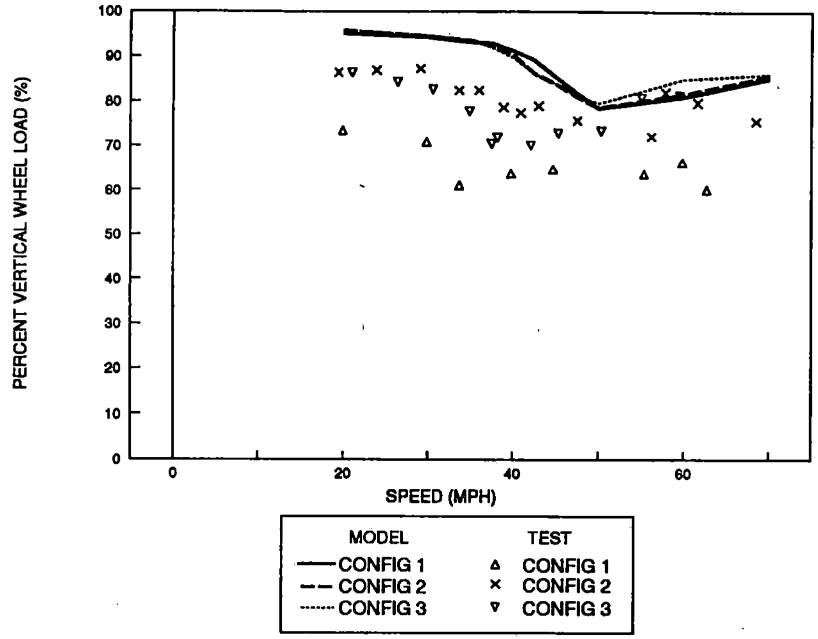

Figure 10. Minimum Wheel Loads (Percent of Static) for the Lead Left Wheel in the Pitch and Bounce Test Zone

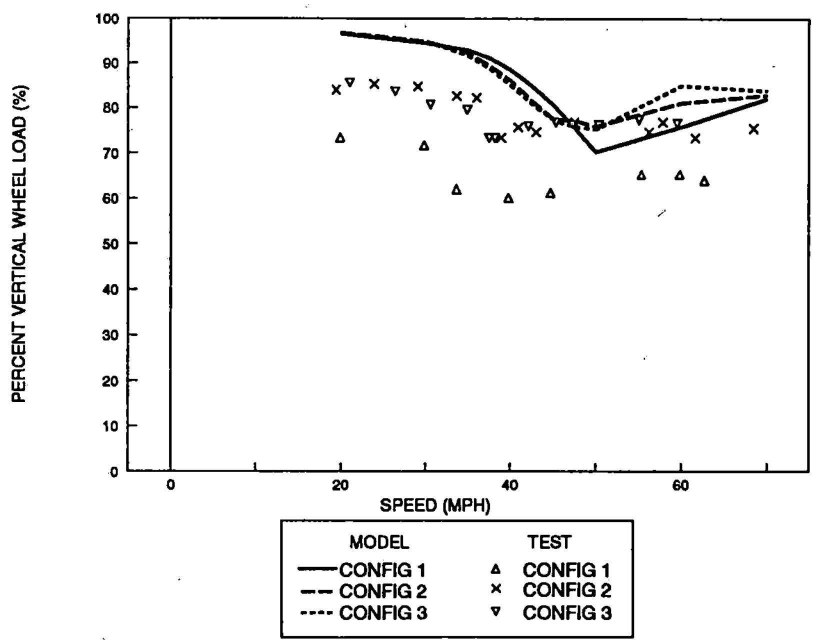

Figure 11. Minimum Wheel Loads (Percent of Static) for the Lead Right Wheel in the Pitch and Bounce Test Zone

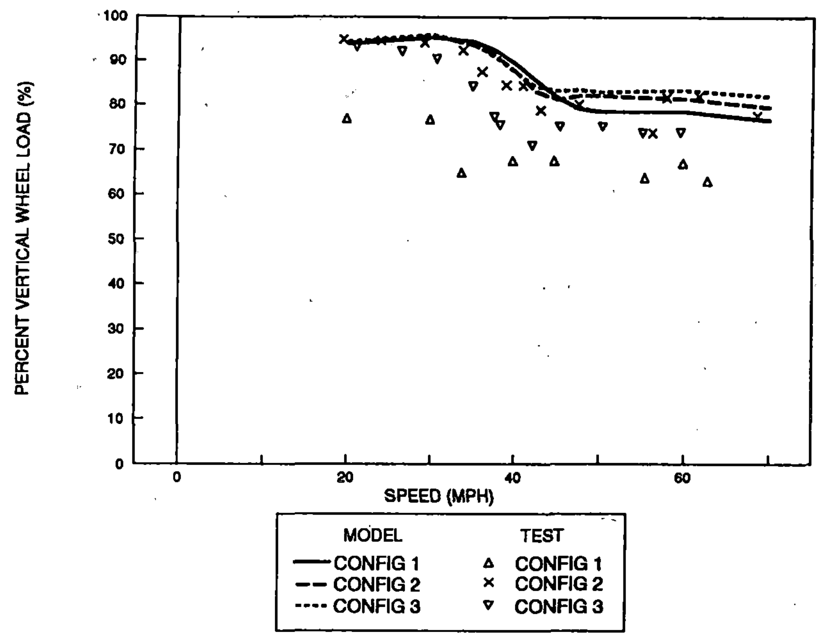

Figure 12. Minimum Wheel Loads (Percent of Static) for the Trail Left Wheel in the Pitch and Bounce Test Zone

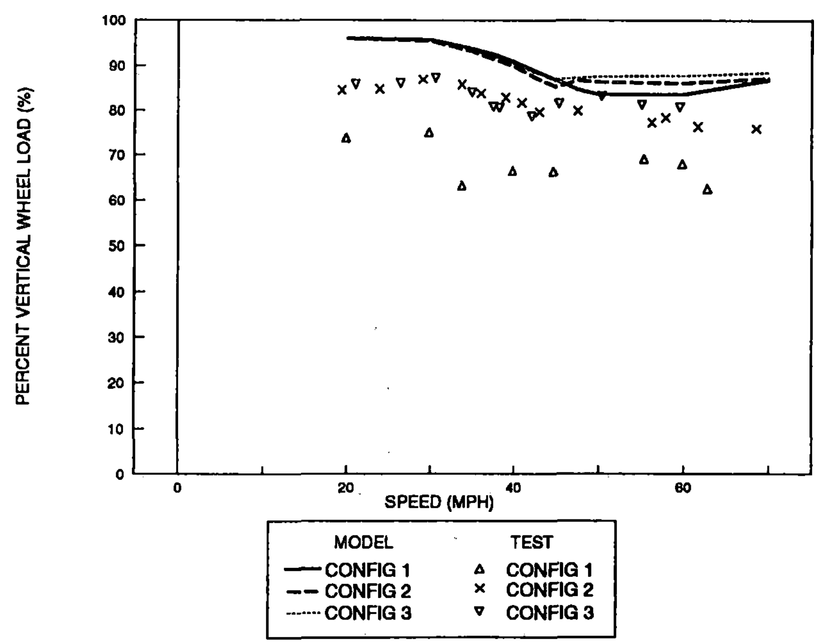

Figure 13. Minimum Wheel Loads (Percent of Static) for the Trail Right Wheel in the Pitch and Bounce Test Zone

The model predictions all show higher minimum loads than the test data. In addition, the resonant speeds are greater, being concentrated at 50 mph. The discrepancy in minimum load could be due to the instrumented wheel sets miscalculating the measured vertical load because of the choice in calibration constant described in Section 6.2.1. The error in resonant frequency is probably the result of the incorrect modeling of the secondary leaf spring vertical suspension. It is suspected that in the NUCARS models, the friction in the simulated leaf spring remained locked up during most of its travel, effectively increasing the overall vertical stiffness and increasing the resonant frequency. Unfortunately, due to limited project funds, a thorough analysis of the problem has not been made.

7.2 TWIST AND ROLL

The twist and roll test zone is similar to the pitch and bounce zone having rail segments 39 feet long raised 3/4 inch in the middle to simulate low joints. In this case however the left and right rails have the low points offset by 19.5 feet to create cross-level variations, as shown in Figure 14.

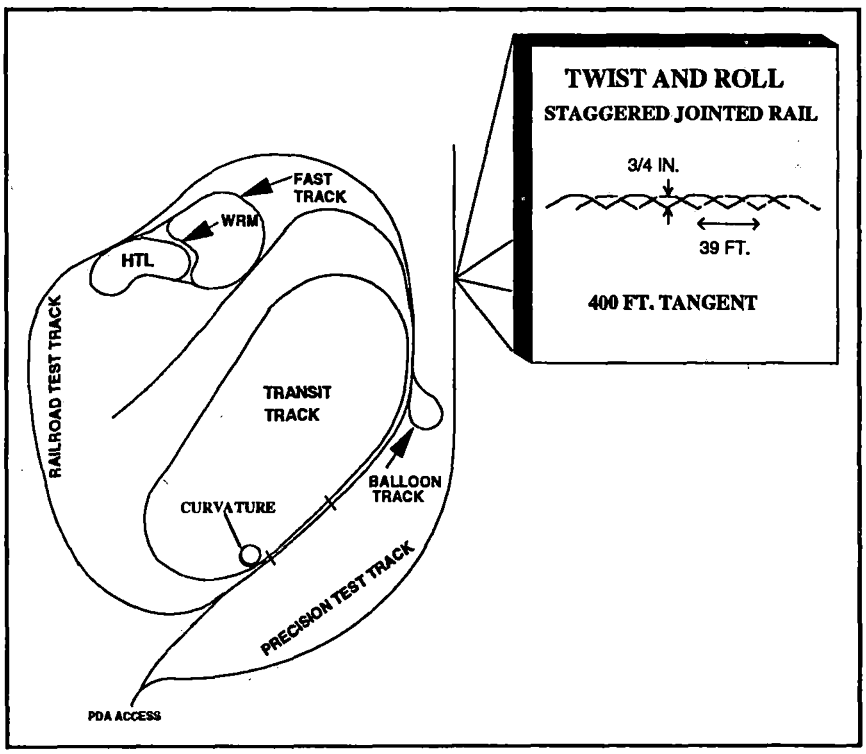

Figure 14. Twist and Roll Test Zone at TTC

Figures 15 and 16 compare the predicted and measured maximum peak-to- peak car body roll angles in the twist and roll test zone. The measured roll angles are all well below the Chapter XI maximum of 6 degrees. The increased loading appears to reduce the maximum angles achieved by a small amount, although the difference is so small (0.4 degrees) that it may be due to the normal variability between test runs. The measured roll resonances appear to be unaffected by the changes in loading, occurring near 10 mph.

The predictions show similarly low roll angles, but the predicted roll resonances are much higher at around 20 mph. This is also probably due to inaccurate modeling of the leaf spring secondary suspension as described in Section 7.1. Again insufficient funds were available to pursue the problem.

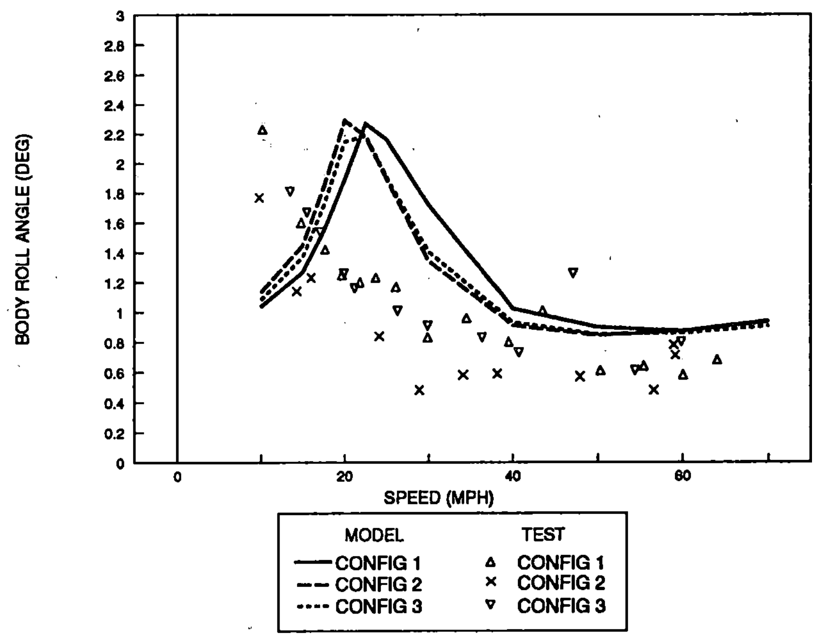

Figure 15. Maximum Peak-to-Peak Lead Body Roll Angles in the Twist and Roll Test Zone

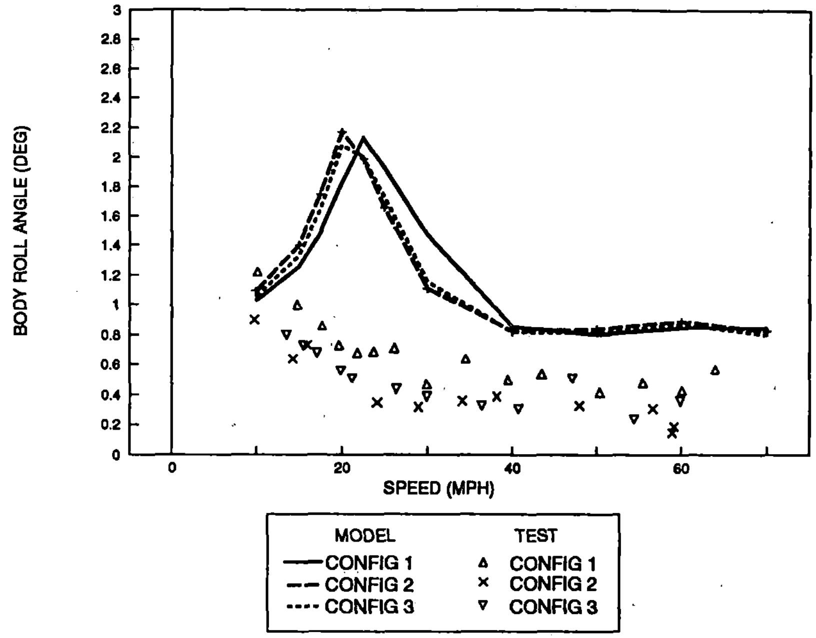

Figure 16. Maximum Peak-to-Peak Trail Body Roll Angles in the Twist and Roll Test Zone

The measured minimum vertical loads are compared to the predictions in Figures 17 through 20. Again good performance is shown with the lowest minimum of 45 percent of the static load being shown in configuration 1, well above the Chapter XI criterion of 10 percent.

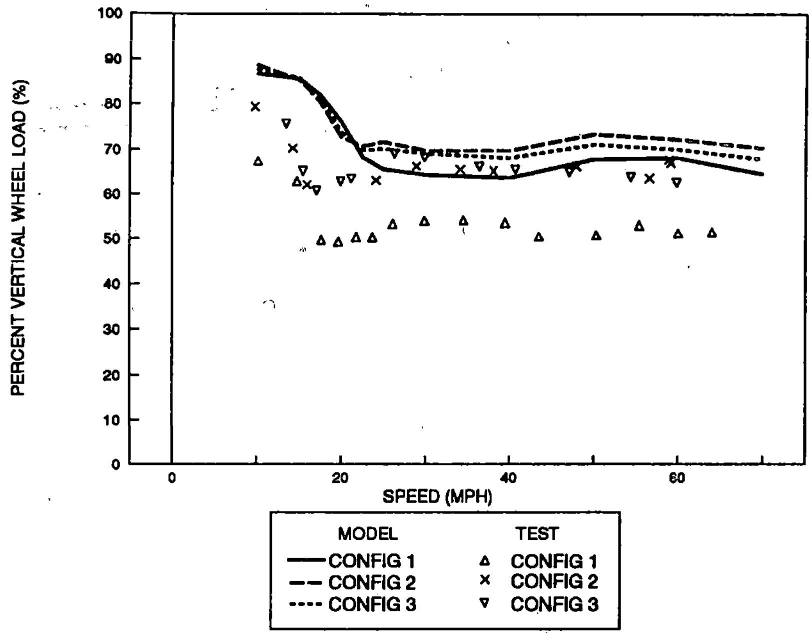

Figure 17. Minimum Wheel Loads (Percent of Static) for the Lead Left Wheel in the Twist and Roll Test Zone

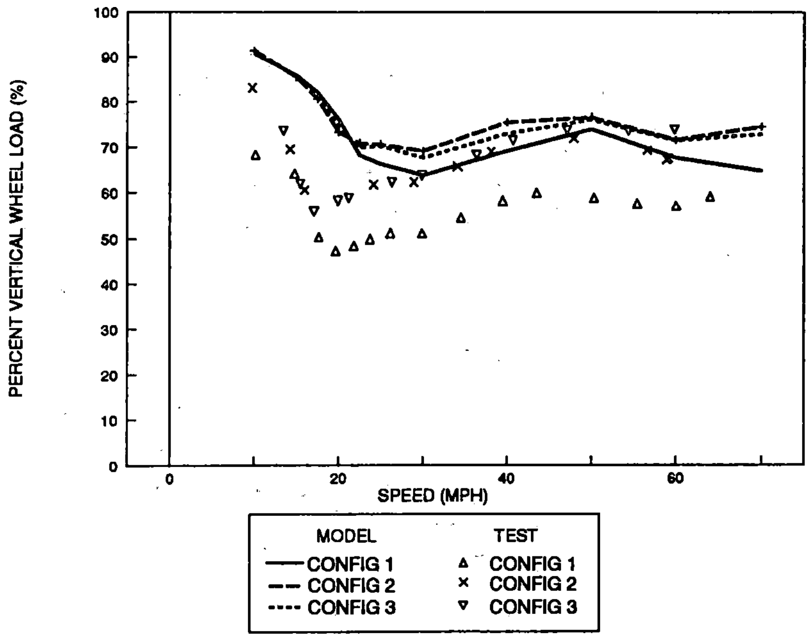

Figure 18. Minimum Wheel Loads (Percent of Static) for the Lead Right Wheel in the Twist and Roll Test Zone

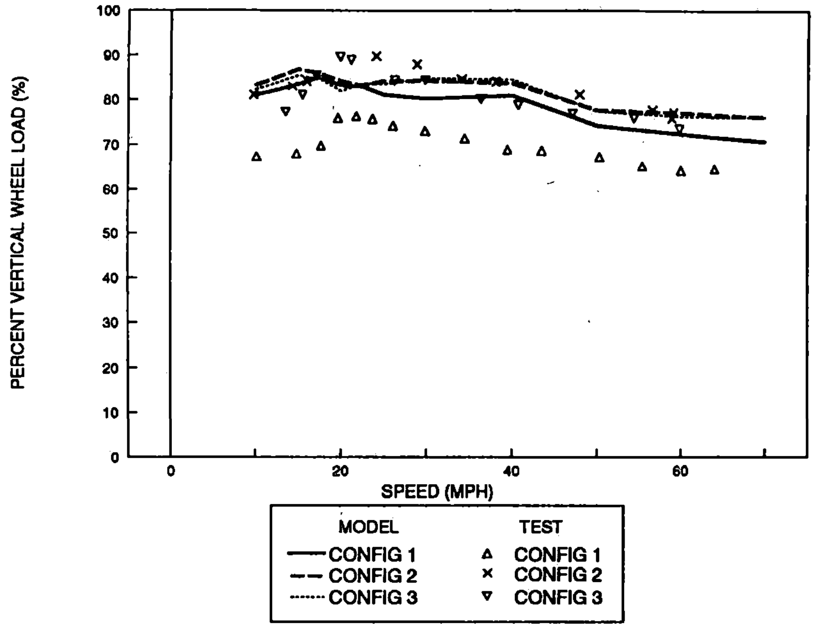

Figure 19. Minimum Wheel Loads (Percent of Static) for the Trail Left Wheel in the Twist and Roll Test Zone

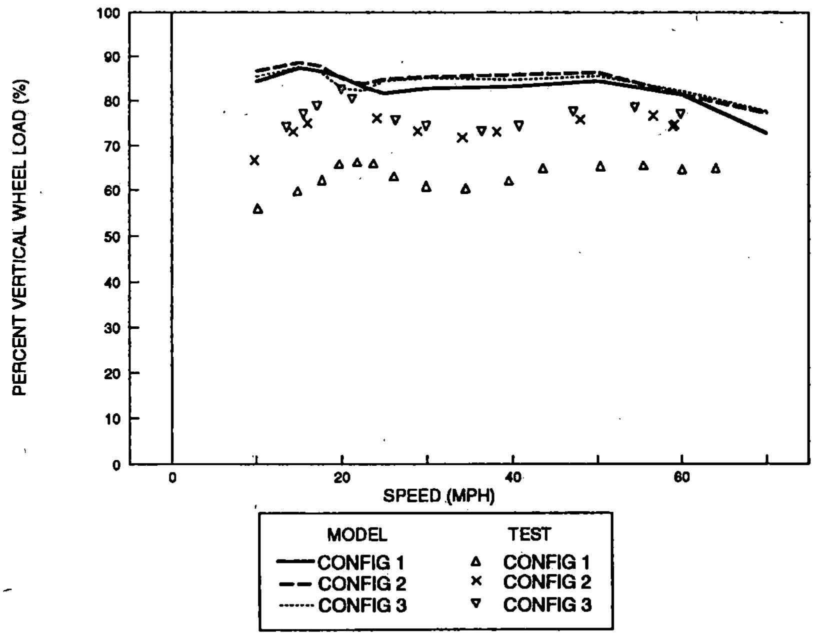

Figure 20. Minimum Wheel Loads (Percent of Static) for the Trail Right Wheel in the Twist and Roll Test Zone

The measured maximum axle sum L/V ratios are also well within Chapter XI criterion of 1.4, with a maximum value of 0.4, as shown in Figures 21 and 22. The test data shows somewhat higher levels than the predictions, but this could be due to the wheel set measurement errors previously mentioned causing a miscalculation of the L/V ratios.

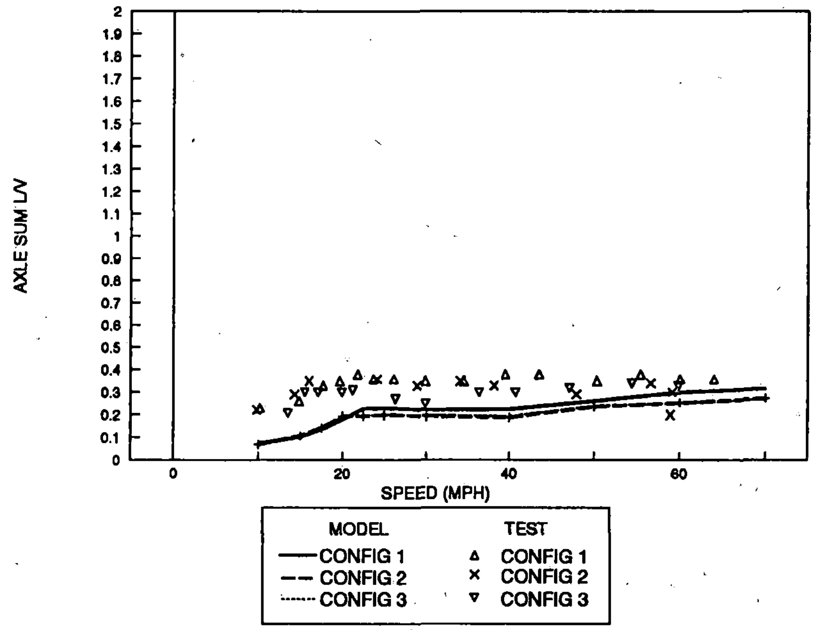

Figure 21. Maximum Axle Sum L/V Ratios on the Lead Axle of the Lead Truck in the Twist and Roll Test Zone

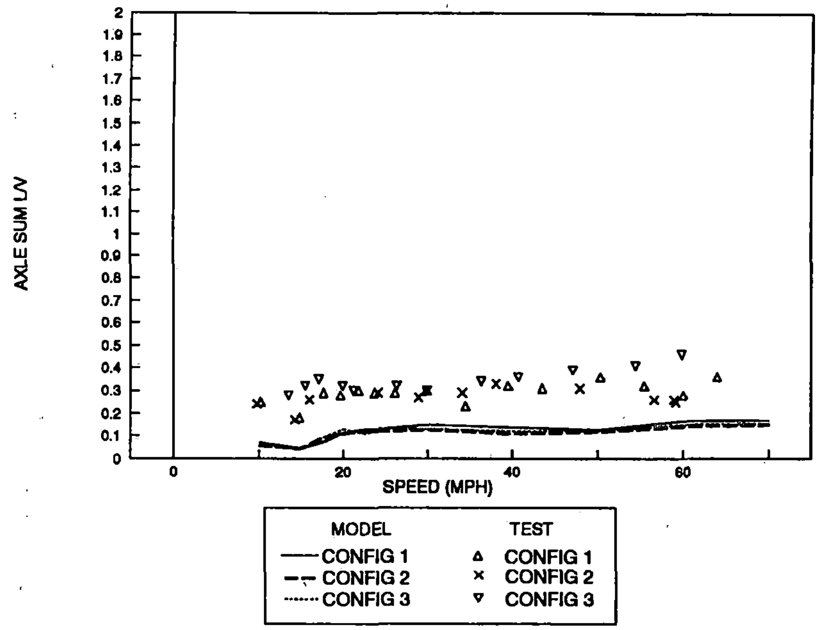

Figure 22. Maximum Axle Sum L/V Ratios on the Trail Axle of the Lead Truck in the Twist and Roll Test Zone

7.3 YAW AND SWAY

The yaw and sway test zone consists of tangent track with the gage widened by 1 inch. Superimposed on this track are five sinusoidal lateral perturbations of 1.25 inch amplitude with a wavelength of 39 feet, as shown in Figure 23.

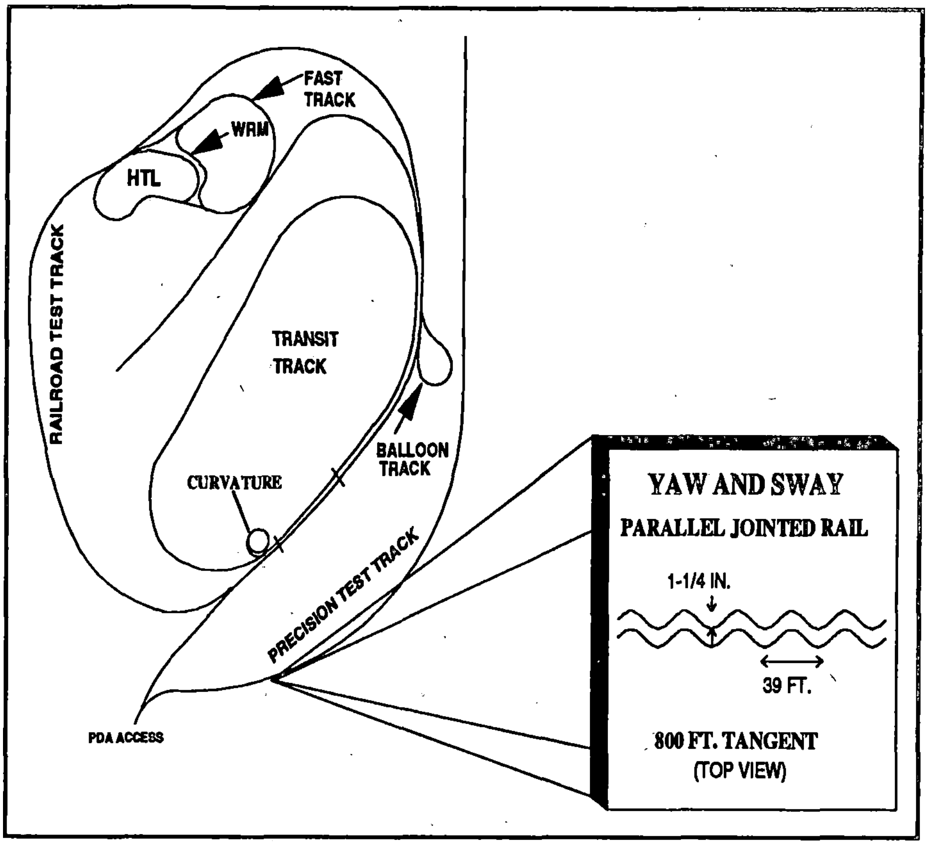

Figure 23. Yaw and Sway Test Zone at TTC

The performance in the yaw and sway test zone is also well within Chapter XI performance criteria. The measured maximum axle sum L/V ratios, shown in Figures 24 and 25, reach a maximum of 0.65 at 65 mph for configuration 1. No clear resonance is apparent for any of the configurations, although a slight increase in L/V occurs at 50 mph for configuration 3. The predicted axle sum L/V ratios for the lead axle are much greater than the measured values but are still well below the Chapter XI criterion of 1.4. Because of budget limitations, no attempt has been made to determine the reasons for this discrepancy. It is possible that if the modeling of the leaf spring is corrected these predictions will improve.

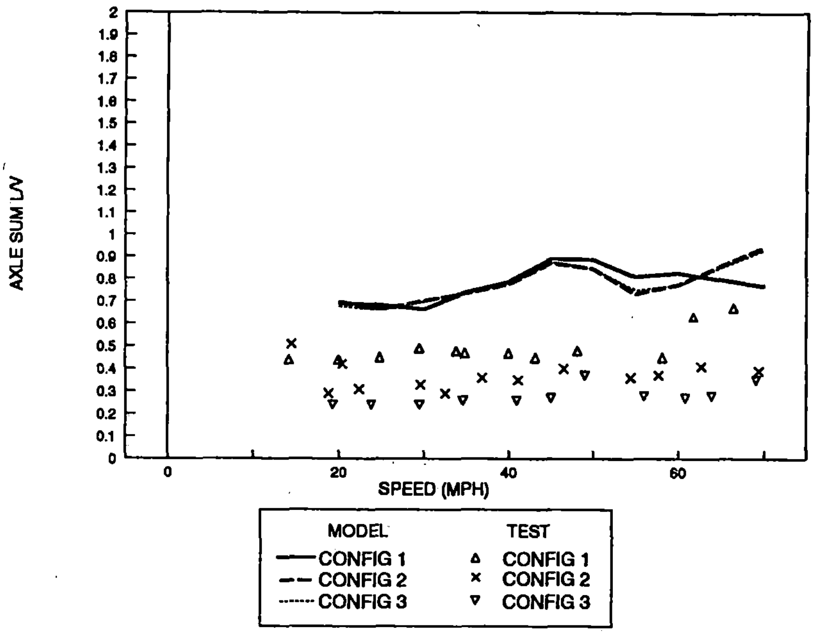

Figure 24. Maximum Axle Sum L/V Ratios on the Lead Axle of the Lead Truck in the Yaw and Sway Test Zone

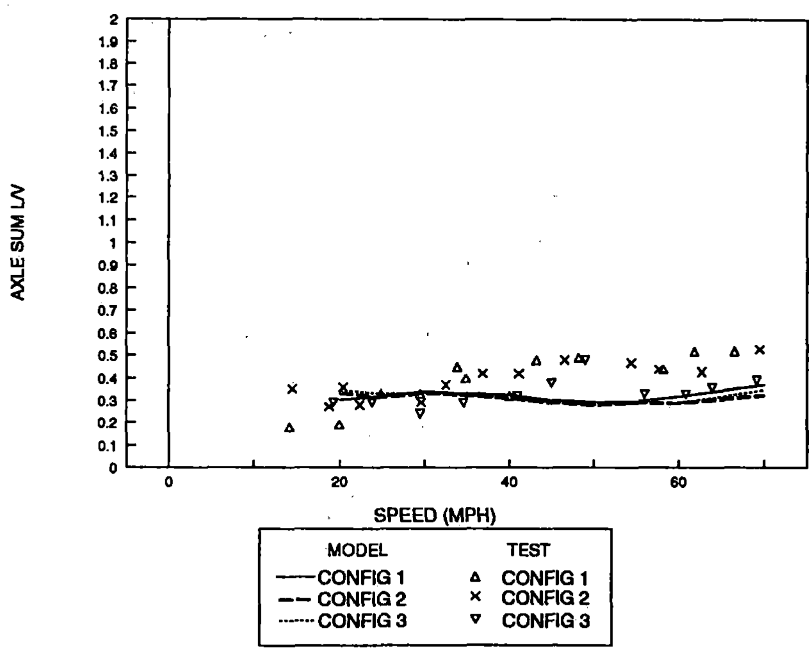

Figure 25. Maximum Axle Sum L/V Ratios on the Trail Axle of the Lead Truck in the Yaw and Sway Test Zone

The measured and predicted truck side L/V ratios, shown in Figures 26 and 27, match much better. The results are all well below the Chapter XI criterion of 0.6.

Performance appears unaffected by the increased loads, with little difference between the three configurations.

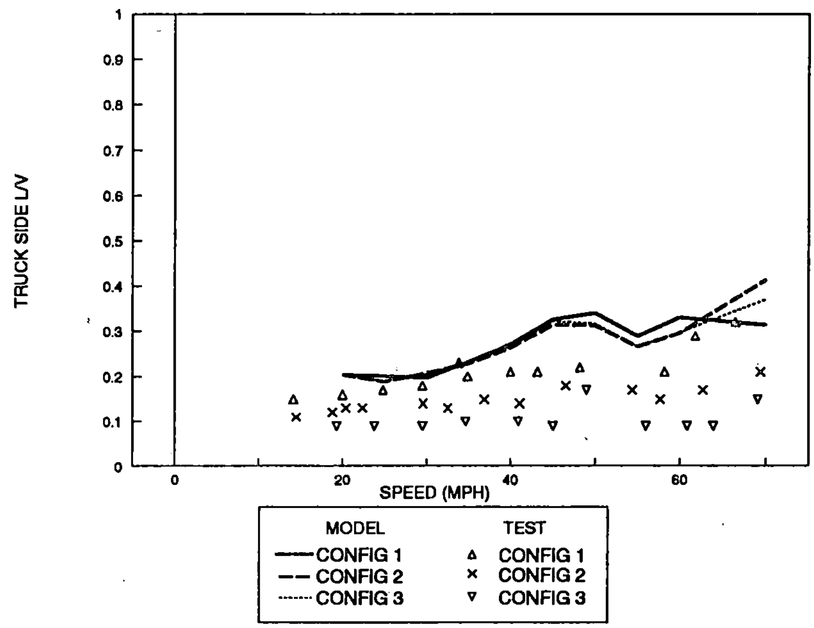

Figure 26. Maximum Truck Side L/V Ratios on the Lead Axle of the Lead Truck in the Yaw and Sway Test Zone

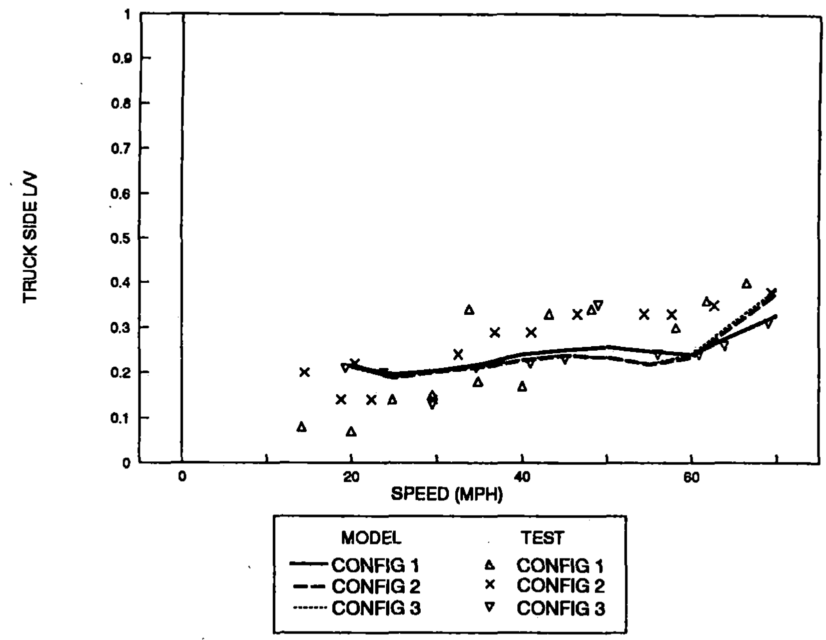

Figure 27. Maximum Truck Side L/V Ratios on the Trail Axle of the Lead Truck in the Yaw and Sway Test Zone

7.4 STEADY STATE CURVING

The steady state curving tests were performed over the 7.5-, 10-, and 12-degree curves at the test loop at the TTC, as shown in Figure 28. Tests were performed with the locomotive running both clockwise and counterclockwise around the loop to balance any possible asymmetries in the test locomotive. The model being symmetric was run only in the clockwise direction.

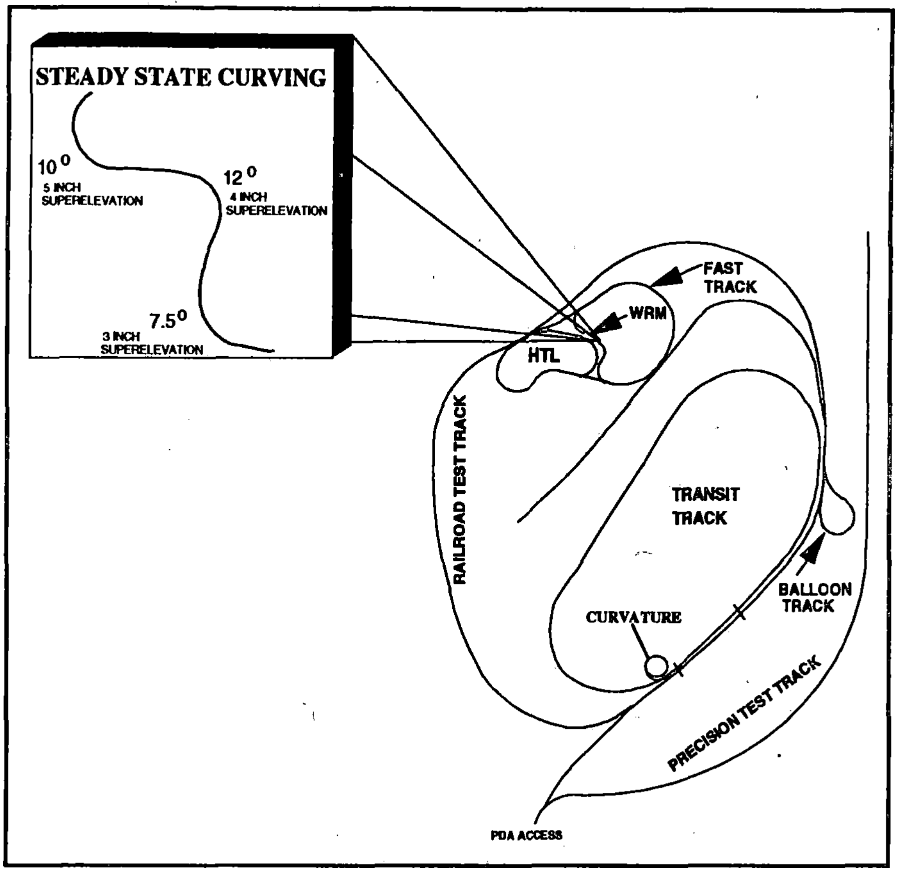

Figure 28. Steady State Curving Test Zones at TTC

The highest individual wheel L/V ratios occurred on the lead flanging wheel for all three curves, as shown in Figures 29, 30, and 31. The maximum measured wheel L/V ratios were all below the Chapter XI criterion of 1.0. The levels appeared to be increased by the loads in configurations 2 and 3. There is a large amount of scatter in the data. This is probably partly due to normal variability in test data and to inaccuraces of the instrumented wheel sets. The 10- and 12-degree curves showed slightly higher L/V ratios than the 7.5-degree curve.

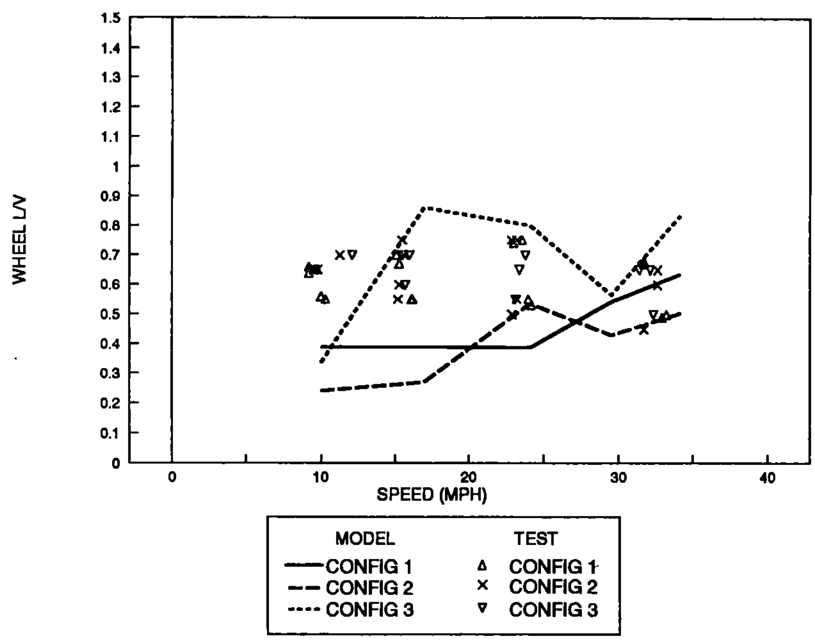

Figure 29. Maximum Wheel L/V Ratios on the Lead Axle Outside (Flanging) Wheel of the Lead Truck in 7.5-Degree Steady Curve Test Zone

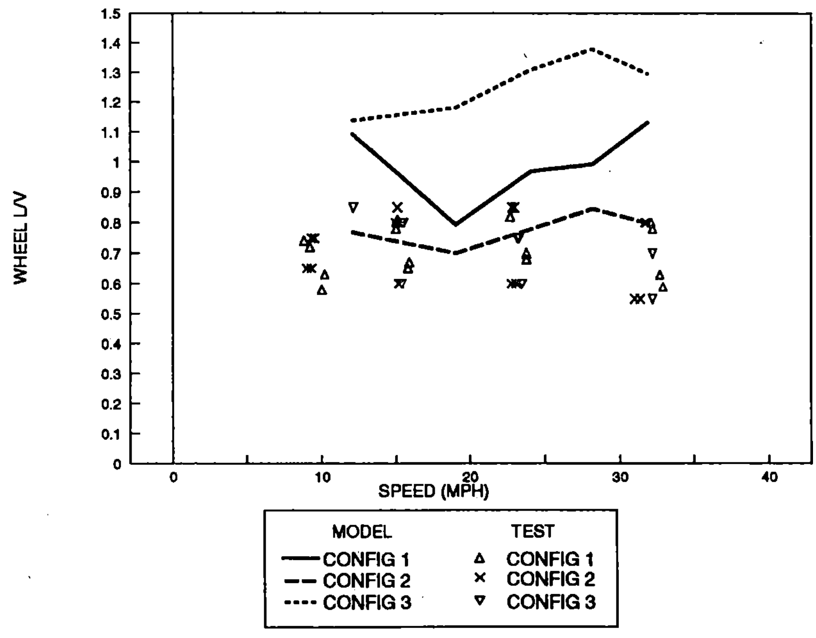

Figure 30. Maximum Wheel L/V Ratios on the Lead Axle Outside (Flanging) Wheel of the Lead Truck in 10-Degree Steady Curve Test Zone

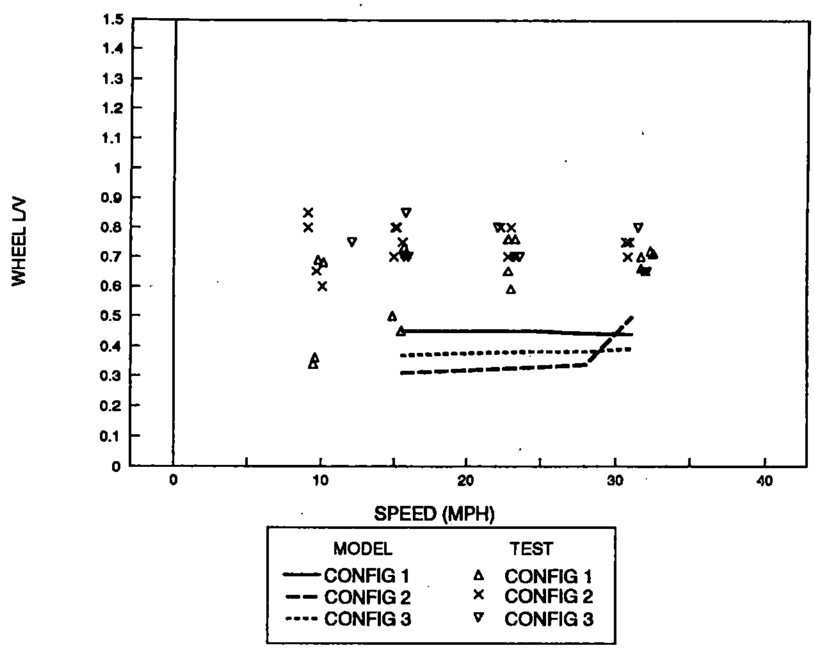

Figure 31. Maximum Wheel L/V Ratios on the Lead Axle Outside (Flanging) Wheel of the Lead Truck in 12-Degree Steady Curve Test Zone

The model in general shows maximum L/V ratios that were less than measured values. This is probably because the simulated track is smooth, while the actual track has minor kinks and joints that result in momentary increases in lateral forces, and hence L/V ratios. Although the data analysis methods are intended to account for some of these anomalies, the experience of previous test programs has shown that the model data is still too smooth. An accurate simulation of the track roughness would probably improve the correlation between test and model predictions. For the 12-degree curve, the model data indicates that maximum wheel L/V ratios decrease with the increased loads of configurations 2 and 3. This is the opposite trend indicated by the test data. The predictions for configurations 1 and 3 in the 10-degree curve appear anomalous, however, with L/V ratios well above the Chapter XI criterion of 1.0. No attempt has been made to identify the reason for this behavior, due to a limited budget.

The measured lead axle maximum axle sum L/V ratios are shown compared to model predictions in Figures 32, 33 and 34. These show similar trends to the wheel L/V ratio data with all values less than the Chapter XI criterion; although, for the 12-degree curve, configuration 3, the values are right at the limiting criterion level of 1.4. The model predictions are again less than the measured values except for the anomalous 10-degree curve data for configurations 1 and 3.

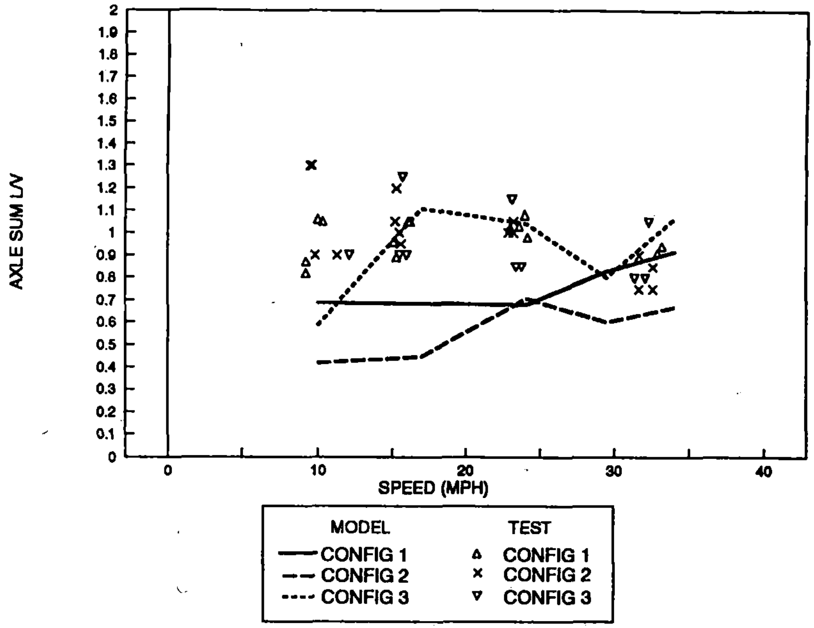

Figure 32. Maximum Axle Sum L/V Ratios on the Lead Axle of the Lead Truck in 7.5-Degree Steady Curve Test Zone

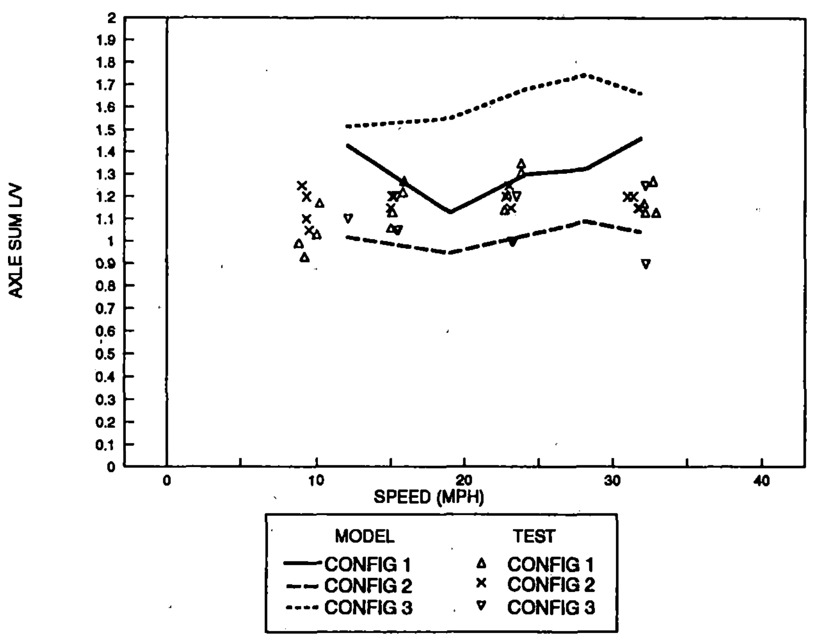

Figure 33. Maximum Axle Sum L/V Ratios on the Lead Axle of the Lead Truck in 10-Degree Steady Curve Test Zone

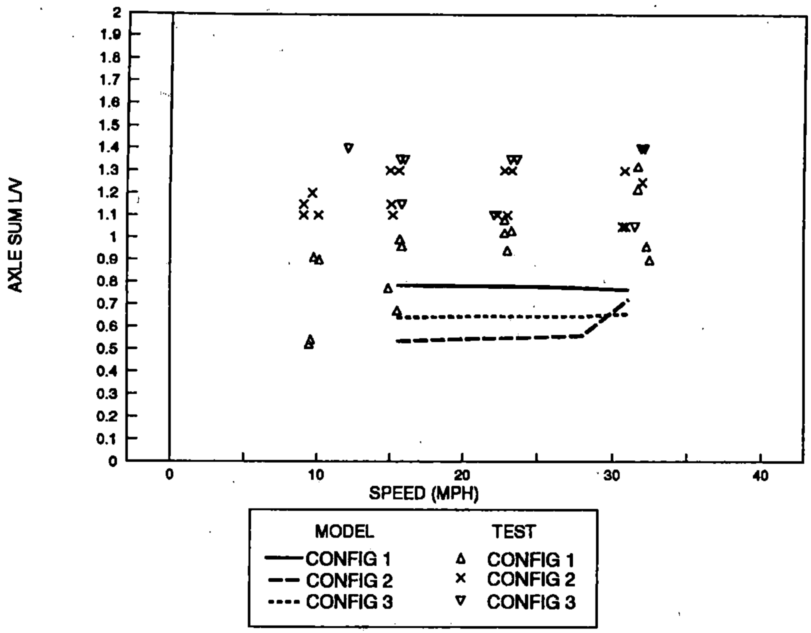

Figure 34. Maximum Axle Sum L/V Ratios on the Lead Axle of the Lead Truck in 12-Degree Steady Curve Test Zone

The test data indicate that the increased loads in configurations 2 and 3 appear to slightly increase the measured maximum L/V ratios. But, again, the model predictions for the 12-degree curve indicate the opposite trend. Sufficient funds are not available to explore this anomaly.

The NUCARS predictions for the 12-degree curve are unusual because the L/V ratios predicted are much less than for the 10- and 7.5-degree curves. This is contrary to what is normally expected. The test data showed the 7.5-degree curve having the lowest L/V ratios and the 12-degree curve the highest, as expected. Sufficient funds are not available to explore this anomaly.

7.5 CURVE ENTRY/EXIT

The curve entry/exit tests were conducted in the spiral entry to the 10 degree WRM loop bypass curve, as shown in Figure 35. The spiral is 88.57 feet long with 5 inches of superelevation. This is not the normal test zone for Chapter XI tests at the TTC but is an experimental test zone with much greater rates of change of superelevation and curvature. This was chosen as it is believed to represent a more realistic test of vehicle safety performance than the normal bunched spiral Chapter XI test zone. It is likely that in the future the Chapter XI test requirement will be revised to be similar to this limiting spiral.

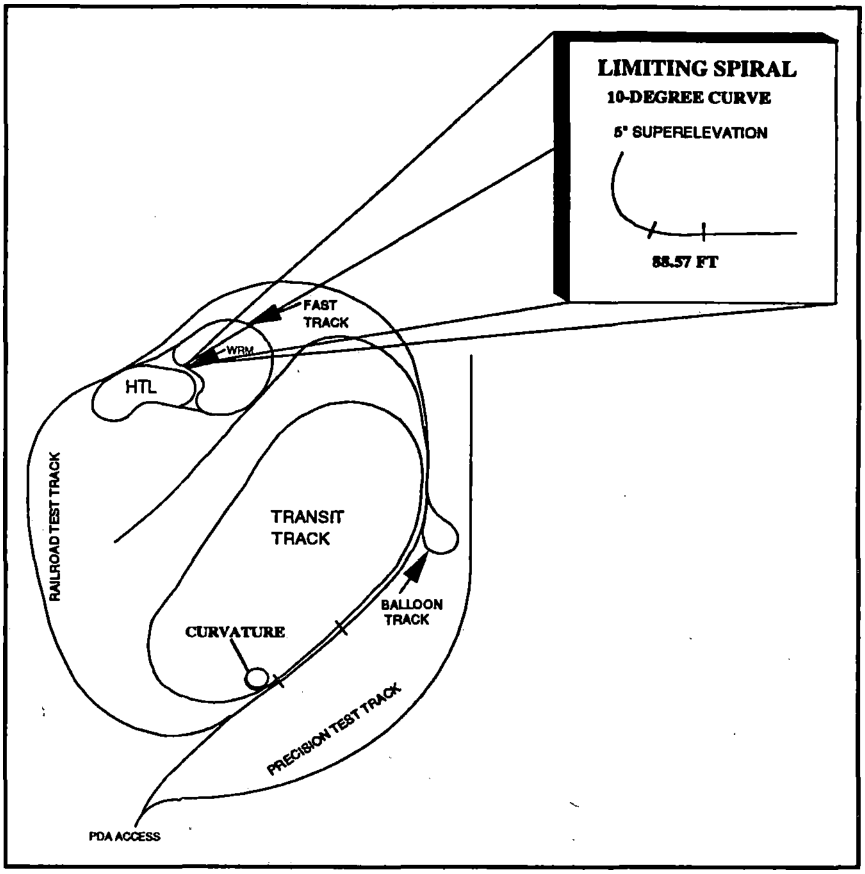

Figure 35. Limiting Spiral Test Zone at TTC

7.5.1 Curve Entry

For curve entry, the maximum measured wheel L/V ratios occurred on the lead axle. As shown in Figures 36 and 37, these were well below the Chapter XI limiting criterion of 1.0. The different loading conditions had little effect on the maximum values recorded, with the heavier axle loadings merely showing their maximum L/V ratios at higher speeds. The model predictions match the overall trends of the test data but with lower maximum values and very little difference between the three configurations.

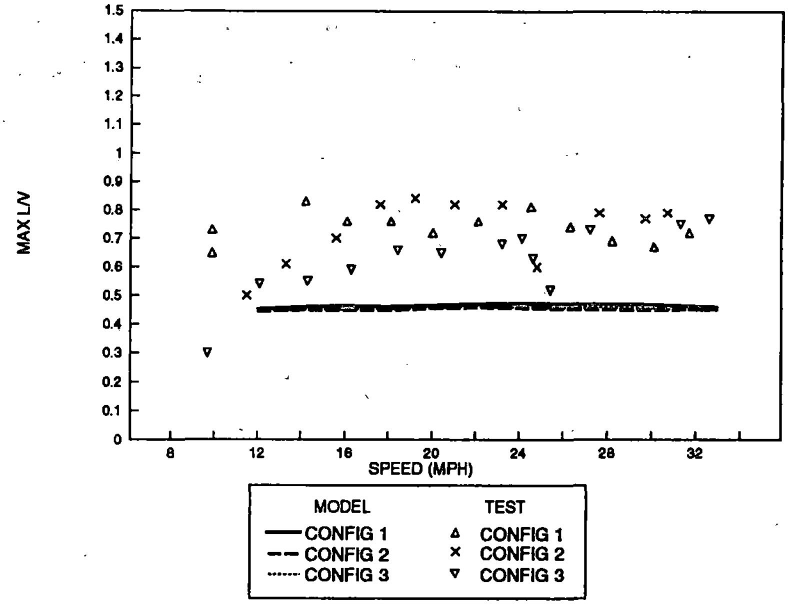

Figure 36. Maximum Wheel L/V Ratios on the Lead Axle Outside (Flanging) Wheel of the Lead Truck in the Limiting Spiral Entry Test Zone

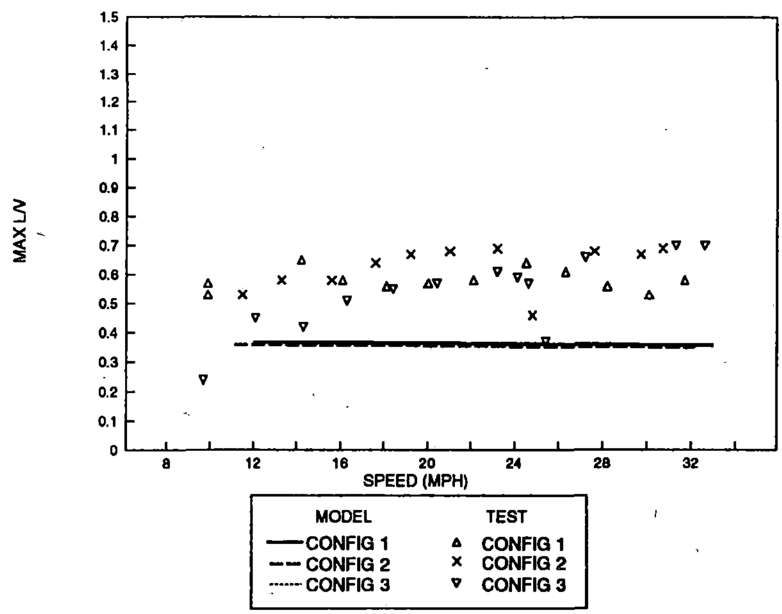

Figure 37. Maximum Wheel L/V Ratios on the Lead Axle Inside (Nonflanging) Wheel of the Lead Truck in the Limiting Spiral Entry Test Zone

The measured minimum percent wheel loads, shown in Figures 38 through 41 were all well above the Chapter XI minimum criterion of 10 percent of the static load. The lowest loads of about 45 percent of static occurred on the lead inside wheel at the highest entry speed of 33 mph. The NUCARS model matched the measured trends well, but predicted minimums were higher than the measured values. This is probably due to the inaccuracies in the vertical force measurements as previously discussed, but may also be due to the errors in modeling the secondary suspension and not modeling the surface roughness of the track.

Neither the model nor the test data shows any significant influences due to the increased loading or changed springs.

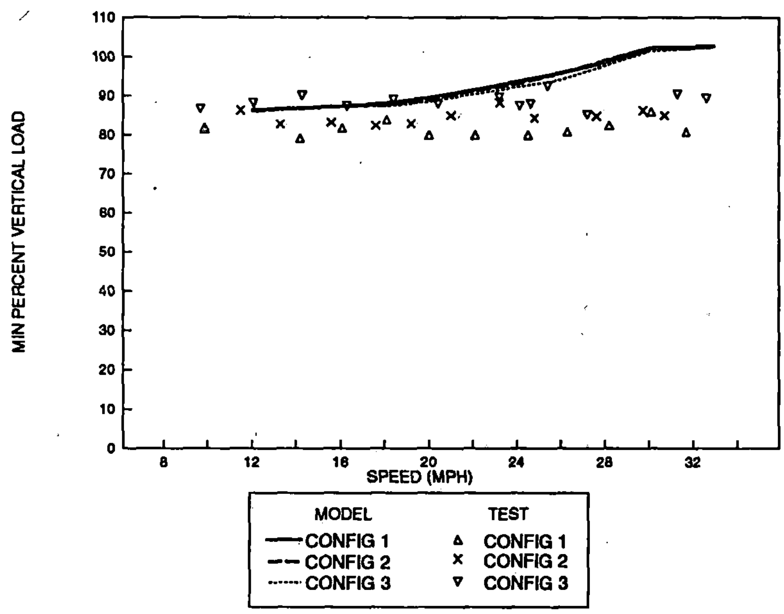

Figure 38. Minimum Wheel Loads (Percent of Static) for the Lead Outside (Flanging) Wheel in the Limiting Spiral Entry Test Zone

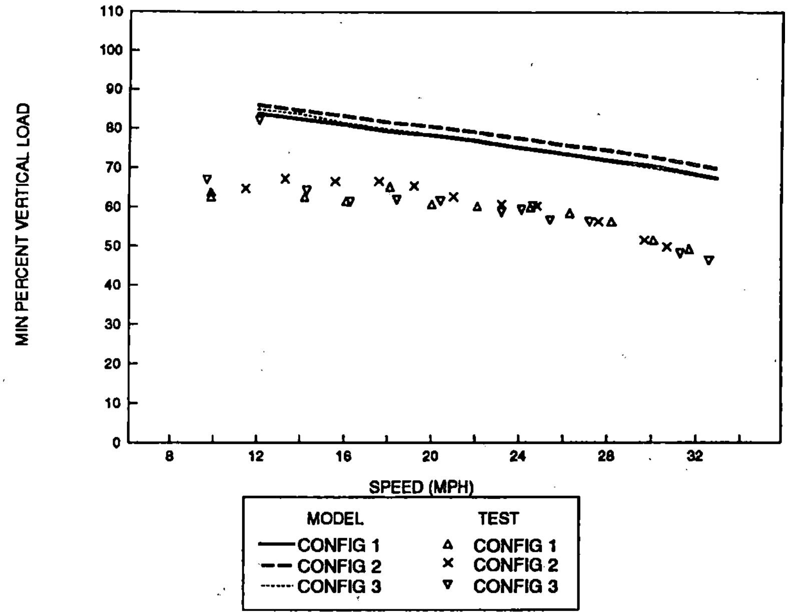

Figure 39. Minimum Wheel Loads (Percent of Static) for the Lead Inside (Nonflanging) Wheel in the Limiting Spiral Entry Test Zone

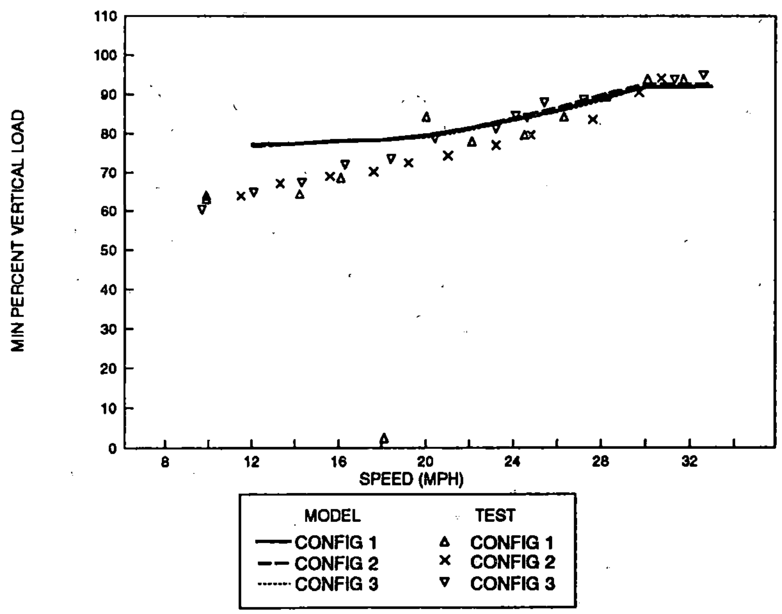

Figure 40. Minimum Wheel Loads (Percent of Static) for the Trail Outside Wheel in the Limiting Spiral Entry Test Zone

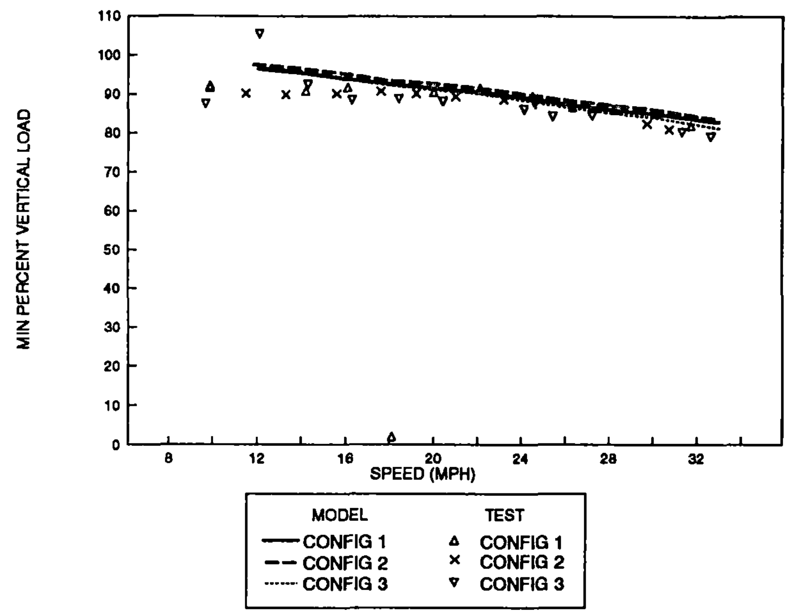

Figure 41. Minimum Wheel Loads (Percent of Static) for the Trail Inside Wheel in the Limiting Spiral Entry Test Zone

7.5.2 Curve Exit

For the curve exit, the measured maximum wheel L/V ratios did exceed the Chapter XI maximum criterion, reaching 1.1 on the lead outside wheel, as shown in Figure 42. This occurred only for configurations 1 and 2, with configuration 3 remaining below the 1.0 criterion level. Thus the addition of weight did not change the vehicle performance and in the case of configuration 3 improved it somewhat. As with previous modeling, the NUCARS results predict considerably lower L/V ratios.

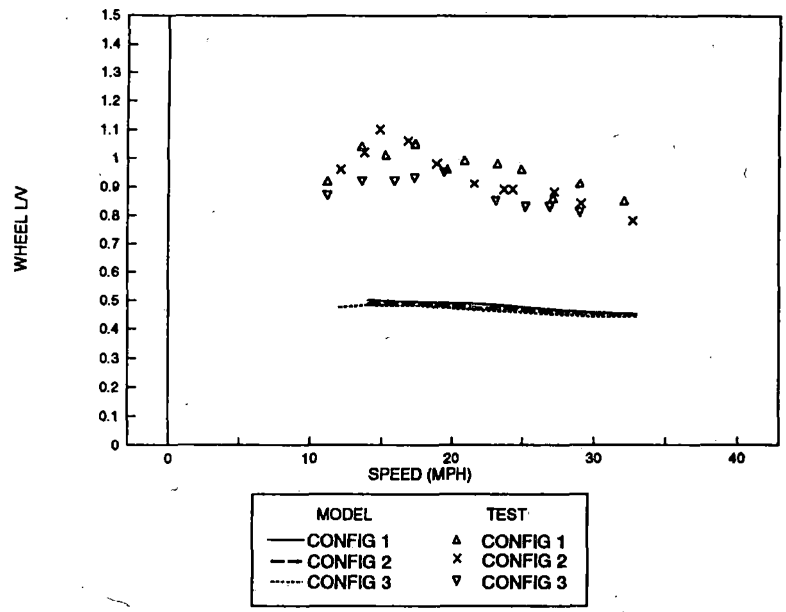

Figure 42. Maximum Wheel L/V Ratios on the Lead Axle Outside (Flanging) Wheel of the Lead Truck in the Limiting Spiral Exit Test Zone

The minimum percent wheel loads shown in Figures 43 through 44 are all well above the Chapter XI minimum with the lowest measured value being near 50 percent on the lead inside wheel at 33 mph. The model results show the same general trends as the test data, but again do not show minimums that are as low.

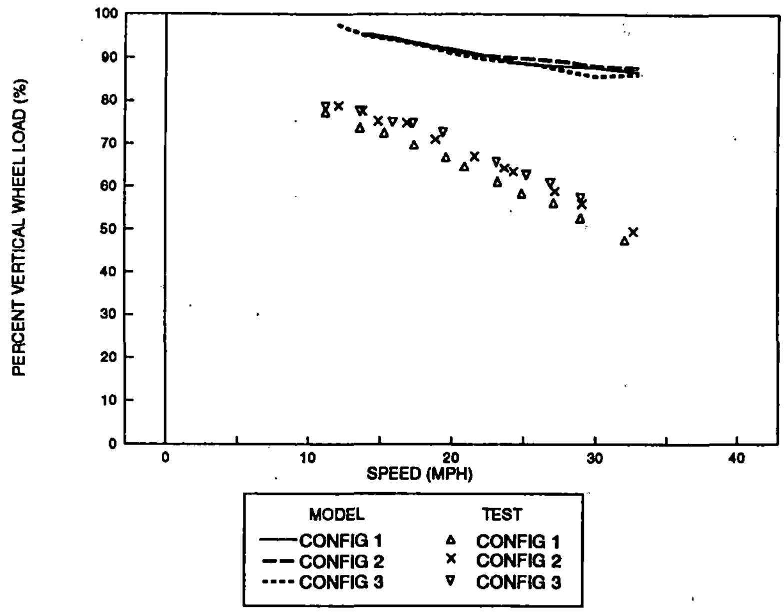

Figure 43. Minimum Wheel Loads (Percent of Static) for the Lead Inside (Nonflanging) Wheel in the Limiting Spiral Exit Test Zone

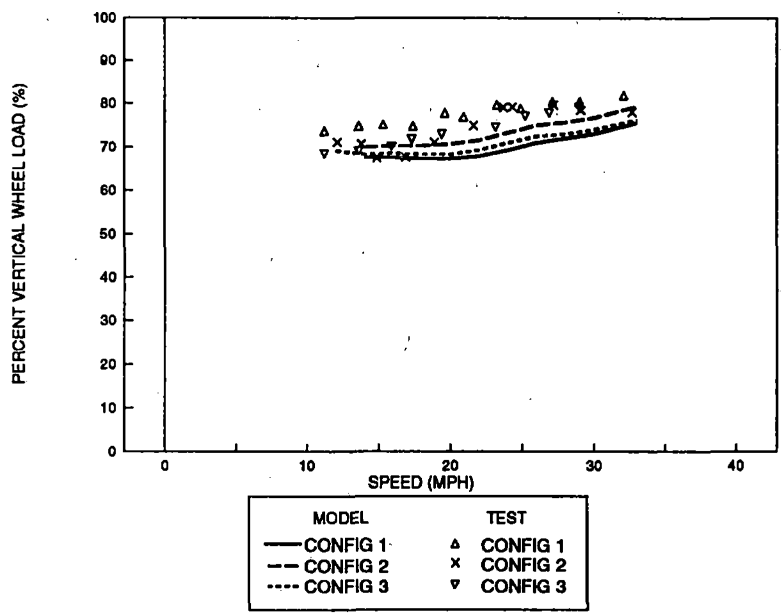

Figure 44. Minimum Wheel Loads (Percent of Static) for the Lead Outside (Flanging) Wheel in the Limiting Spiral Exit Test Zone

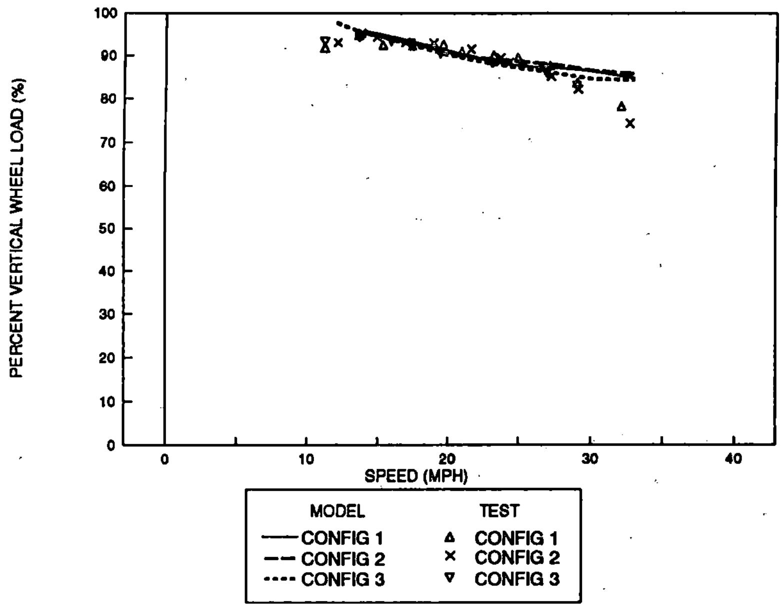

Figure 45. Minimum Wheel Loads (Percent of Static) for the Trail Inside Wheel in the Limiting Spiral Exit Test Zone

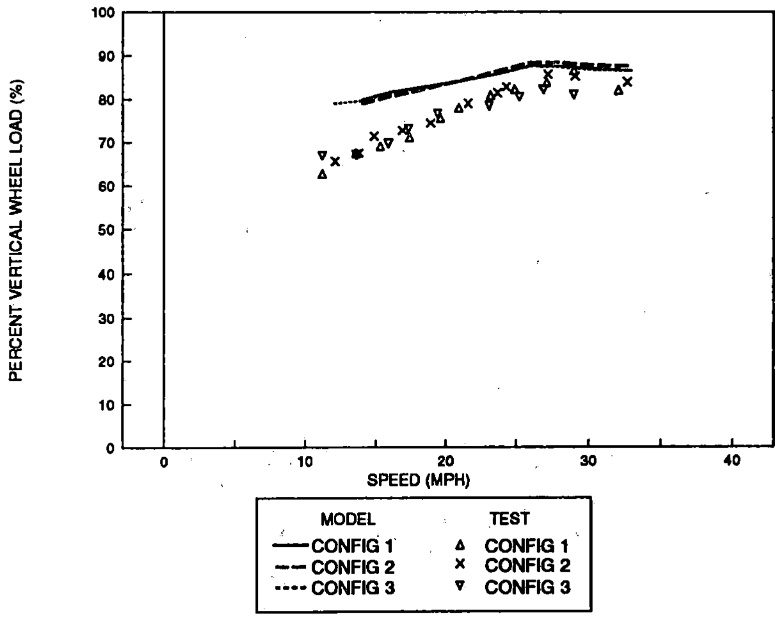

Figure 46. Minimum Wheel Loads (Percent of Static) for the Trail Outside Wheel in the Limiting Spiral Exit Test Zone

7.6 DYNAMIC CURVING

The dynamic curve is built in a 10-degree curve with 4 inches of superelevation. A sinusoidally varying cross level of 1.0 inches peak-to-peak is built into the track in the same manner as the twist and roll test zone by raising the rails 0.5 inches in the center of each 39-foot rail section, as shown in Figure 47. In addition, at each low point in the outside rail of the curve, the track gage is widened by 0.5 inch. These combined vertical and lateral perturbations are installed in 200 feet of the test curve.

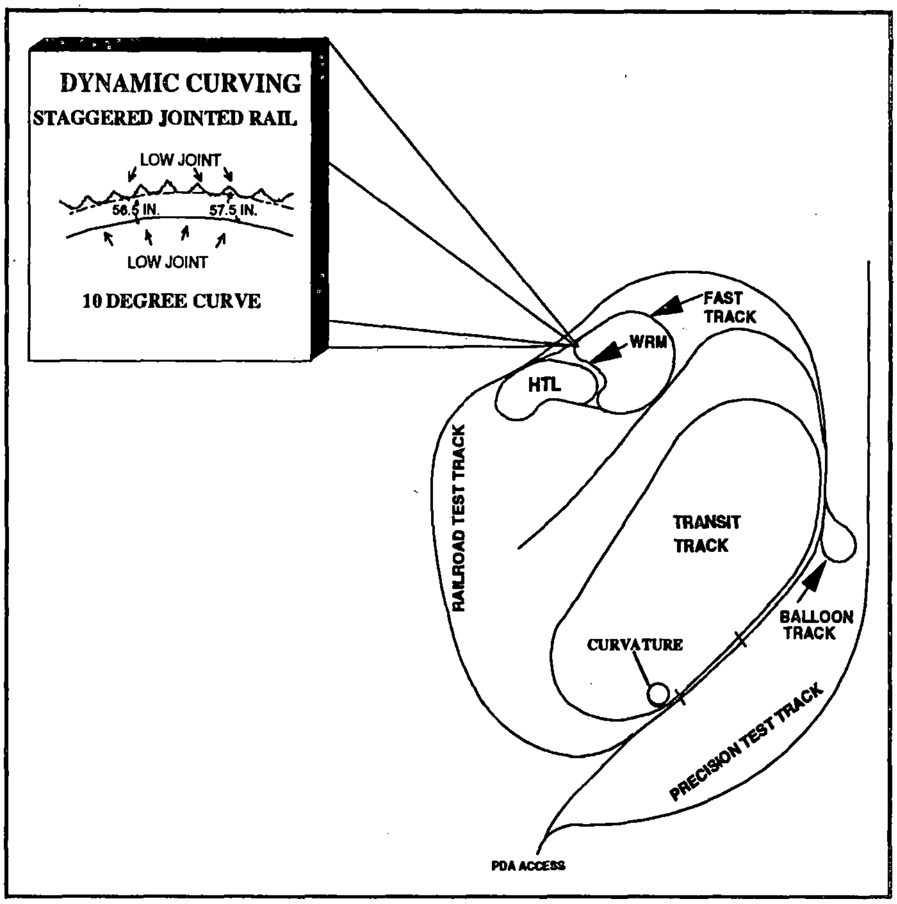

Figure 47. Dynamic Curving Test Zone at TTC

Tests were performed in both clockwise and counterclockwise directions around the dynamic curve test zone. For the most part, results were similar for the two directions of travel; therefore, only the worst case data from each direction of travel is presented here.

The maximum single wheel L/V ratio of slightly greater than 1.0 was measured on the lead right (outside) wheel of the locomotive in configuration 1 while traveling clockwise in the dynamic curve at 12 mph (see Figure 48). The results for the other two configurations are similar but just less than the 1.0 Chapter XI criterion. The test results show a slight decrease with speed. The model predictions show a different trend, increasing with speed with all configurations similar. The differences between the model and test results are probably due to the incorrect modeling of the leaf spring and not accurately simulating the surface roughness of the tracks.

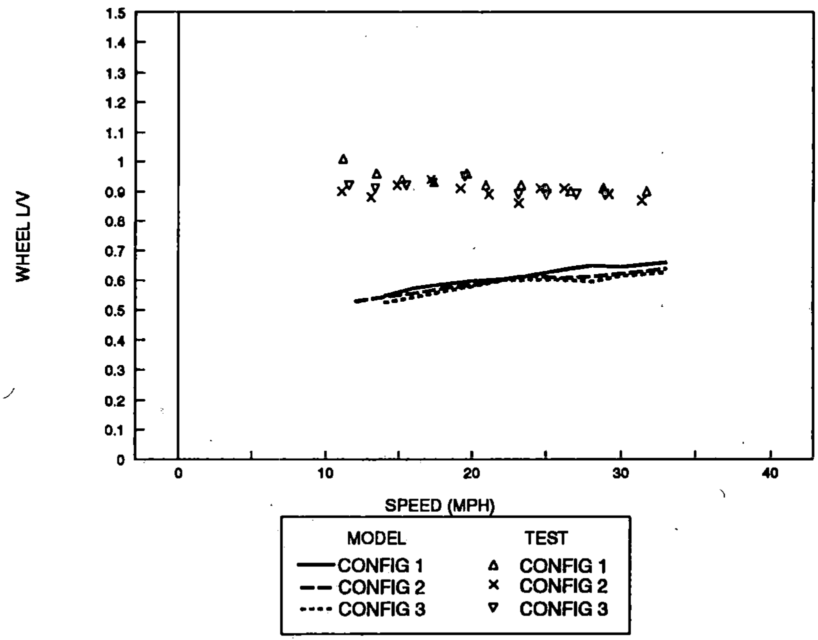

Figure 48. Maximum Wheel L/V Ratios on the Lead Axle Outside (Flanging) Wheel of the Lead Truck in the Clockwise Dynamic Curve Test Zone

The maximum axle sum L/V ratios were measured on the lead axle while traveling clockwise, as shown in Figure 49. All three configurations show maxima above a L/V of 1.5 near 32 mph. This is just greater than the Chapter XI criterion of 1.4. All three configurations show similar performance, with an increasing trend with speed. This trend is matched by the model, although the model predicts much lower maximum values.

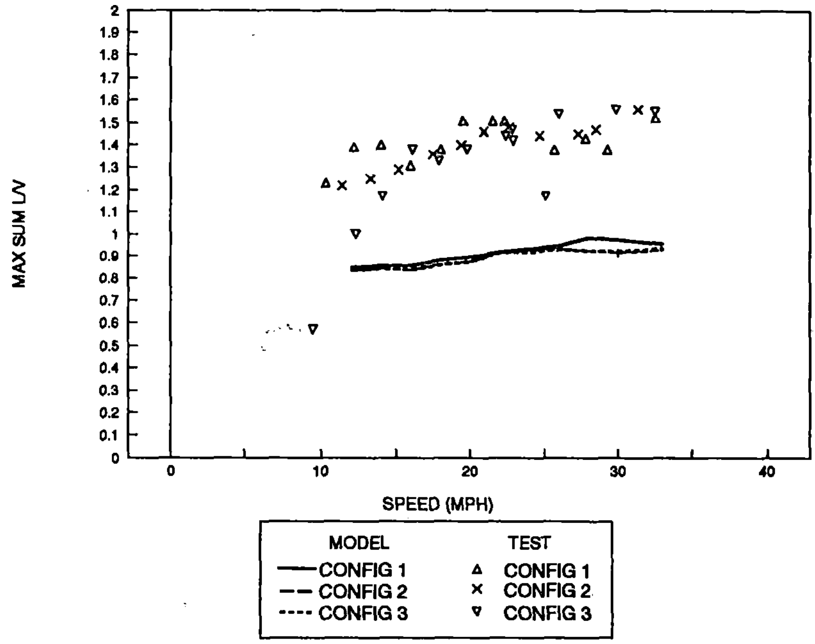

Figure 49. Maximum Axle Sum L/V Ratios on the Lead Axle of the Lead Truck in the Clockwise Dynamic Curve Test Zone

The minimum wheel loads remained well above the Chapter XI criterion of 10 percent of the static load. The minimum was measured on the lead inside wheel at 32 mph for configuration 1 while traveling counterclockwise, as shown in Figure 50. There was no significant difference in the results for the three configurations, with the model matching the downward trends with speed. The model showed much less unloading than the test. This partly explains the lower predicted L/V ratios. With higher minimum loads, for the same lateral load, the L/V ratio would be lower.

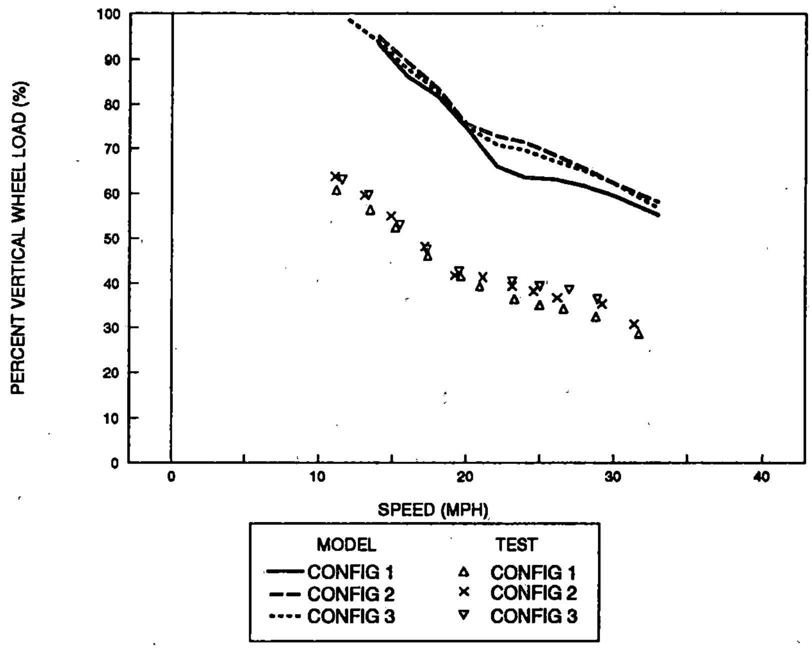

Figure 50. Minimum Wheel Loads (Percent of Static) for the Lead Inside (Nonflanging) Wheel in the Counterclockwise Dynamic Curve Test Zone

The maximum peak-to-peak body roll angles of 1.3 degrees were measured at 12 mph for configuration 3 while running counterclockwise, as shown in Figure 51. The results for the other two configurations are very similar and are well below the Chapter XI criterion of 6 degrees. Similar to the twist and roll test results, the model predictions are quite different, showing resonances between 20 and 25 mph. This partially explains some of the other model discrepancies. With the roll behavior so different, it cannot be expected that the measured and predicted L/V data would show similar trends.

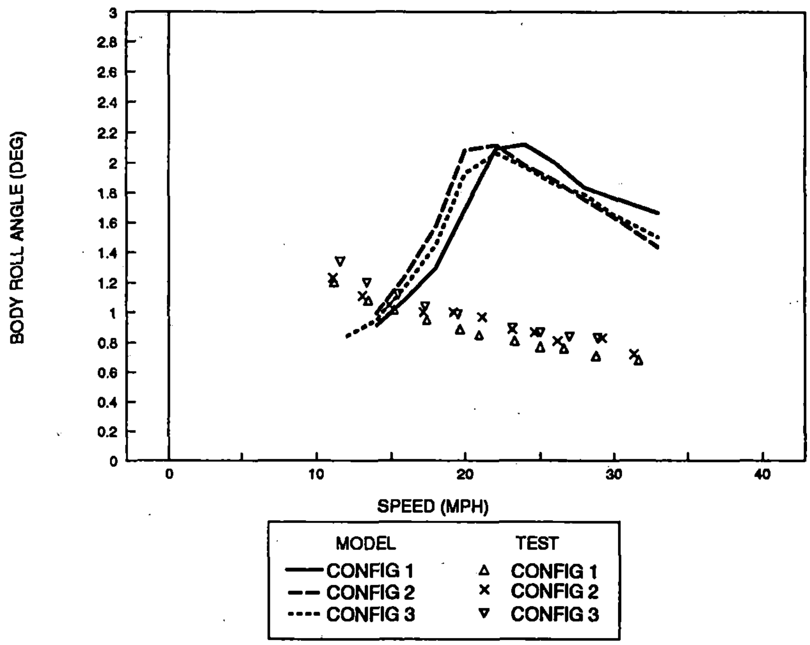

Figure 51. Maximum Peak-to-Peak Lead Body Roll Angles in the Counterclockwise Dynamic Curve Test Zone

All of these results show that there is no significant difference between the three different configurations. Although the measured L/V ratios exceeded the Chapter XI criteria in a few cases, there is no evidence to show that this is due to a change in configuration. The amount by which the measurements exceed the criteria is probably within the range of accuracy for the L/V measurements.

8.0 CONCLUSIONS AND RECOMMENDATIONS

8.1 VEHICLE CHARACTERIZATION

The suspension characterizations initially appeared successful. Characteristics were identified for all suspension components and body flexible modes. Results of the track tests however indicate that the characteristics for the leaf spring are incorrect. It appears that the friction level used in the model is too great, causing the leaf spring to "lock up."

A simple analysis confirms the suspicion that the leaf spring is not functioning correctly in the model. The test results for configuration 1 in the bounce zone indicated a resonant speed around 32 mph which corresponds to a resonant frequency of 1.2 Hz for the 39 foot wavelength input. NUCARS predicted 50 mph resonant speed which corresponds to 1.9 Hz resonance. If the coil springs and the leaf springs were both functioning in unison, the total effective spring rate would be calculated as follows:

$$\text{Effective Stiffness, } K_3 = \frac{1}{\left[\frac{1}{[4\times K_1]}+\frac{1}{[2\times K_2]}\right]} = 19845\text{lb/in}$$

Where: K_1 = Coil Spring Stiffness (8,200 lb/in)
K_2 = Leaf Spring Stiffness (24,000 lb/in)

The resonant frequency in bounce for this spring rate would then be:

$$\text{Resonant Frequency, } F = \frac{1}{2\pi}\sqrt{\frac{K_3}{M}} = 1.3\text{Hz}$$

Where: M = mass of half the body plus one bolster and truck frame (279 lb-s^2/in)

This corresponds closely to the actual bounce frequency found during the track tests.

If however the leaf spring remained locked up, only the coil springs would be effective leading to a resonant frequency in bounce of:

$$\text{Resonant Frequency, } F = \frac{1}{2\pi}\sqrt{4\times\frac{K_1}{M}} = 1.7\text{Hz}$$

This frequency is close to that predicted by the model. Examination of the model results showed much less spring deflection than was found during the tests. This indicates that the leaf spring friction simulated in the model is incorrect, causing the spring to remain locked up. The locked up leaf spring in the model would also explain discrepancies in the NUCARS predictions for twist and roll and dynamic curving test zones. Again, the increased effective stiffness would shift one resonant frequency higher. For this case a simple analysis can't be made because the roll motion is a function of both vertical and lateral suspensions.

To verify these simple analyses, the NUCARS model of the locomotive in configuration 1 was modified to have much less friction in the leaf spring. In addition the means of simulating the friction hysteresis loop of the spring was modified. Previously this was done with a defined friction envelope with the transfer from upper to lower bounds simulated by a linear viscous damper. The new simulation was made using an exponential decay function to accomplish this transfer. This method was originally developed for simulating the leaf spring suspension in the 2-axle frontrunner car. This method had proved troublesome and had been temporarily removed from NUCARS. Recent improvements to the method have permitted reinstalling this friction simulation into NUCARS.

Figures 52 and 53 shows the results of simulated speed sweeps over continuous 39-foot perturbations with parallel low rail joints. The original friction model shows minimum wheel loads are attained near 50 mph, while the modified model shows a minimum some 10 mph lower. With further adjustments, it is expected that these minimums would occur nearer the 30 mph speed at which the minimum loads were measured during the track tests. These adjustments would be to both the friction levels, and to the pitch and roll moments of inertias. The pitch and roll moments of inertia were originally derived from the results of the MSU tests, in conjunction with the original leaf spring model. Changes to the leaf spring model require a re-examination of the moments of inertia.

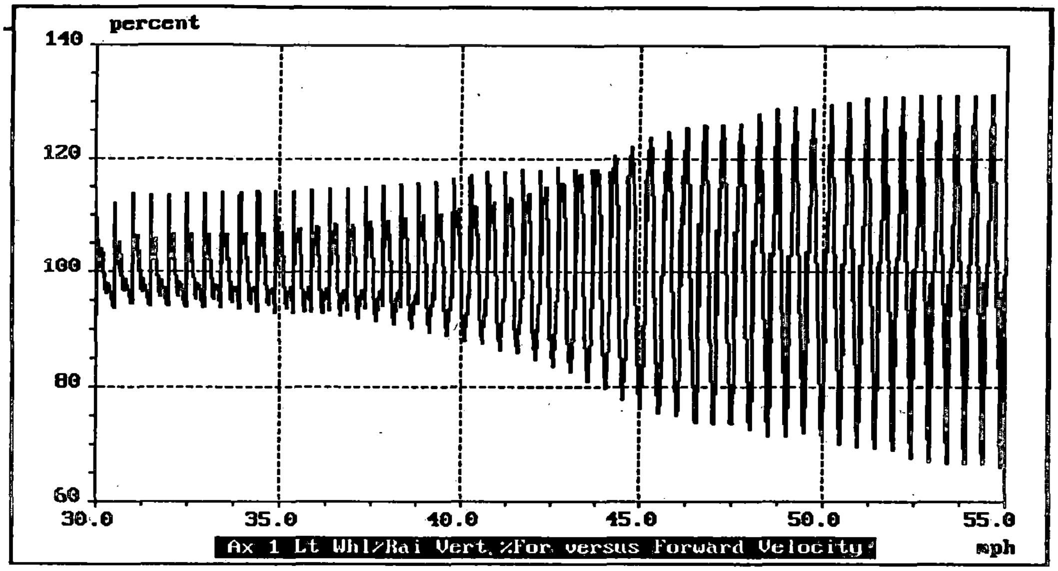

Figure 52. Predicted Minimum Vertical Wheel Load in Original NUCARS System File

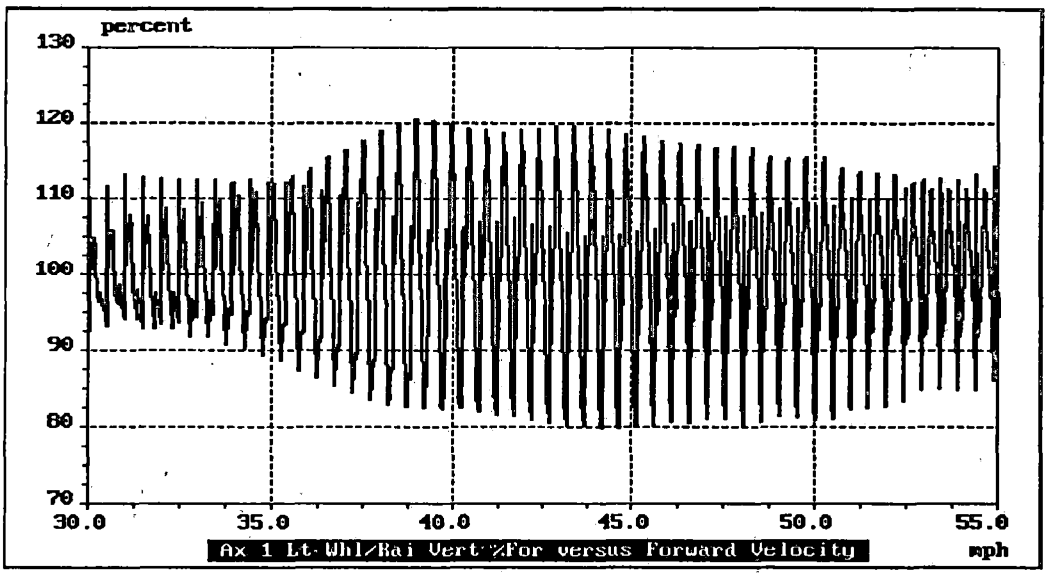

Figure 53. Predicted Minimum Vertical Wheel Load for NUCARS System File with Reduced Leaf Spring Friction

8.2 NUCARS PREDICTIONS

Disregarding the problems with modeling the leaf spring vertical characteristics, the NUCARS modeling showed very little difference between the three configurations. This general result is supported by the track tests which also showed little difference between the configurations.

To improve the match between model and test results, a few improvements need to be made. First, the leaf spring modeling needs to be corrected as previously mentioned. Second, an ability to simulate the random track roughness needs to be included. It has been noted in previous test programs that the extreme peaks in vertical and lateral wheel/rail forces were not accurately simulated unless the track roughness was included.[1,2,3] This had previously been addressed by performing simulations using track input data measured with an inertial based track geometry system. A method should be developed to superimpose a random track roughness input onto the normal NUCARS track inputs.

An investigation should also be made into the discrepancies between test and model for the steady curve. The model predicted lower L/V's in the sharp curve than the shallower curves, contrary to normal expectations and test results.

8.3 LOCOMOTIVE DYNAMIC PERFORMANCE

The track test results show that the locomotive performance in all configurations is within Chapter XI safety criteria for most of the tested conditions. Chapter XI L/V criteria were exceeded only in the curve exit and the dynamic curve test zones.

Although rigorous estimates of the accuracy of the instrumented wheel sets are not available, it is probable that the criteria were exceeded by amounts that were within the measurement accuracy of the system. As noted in Section 6.2.1, the measurement of the vertical forces were likely to be underestimated for all nonflanging wheels. This would in turn cause the L/V ratios to be over estimated for any wheel not in flange contact. This could result in over estimates of the axle sum L/V ratios, but it is unlikely to change the measurement of the wheel L/V ratios for flanging wheels. Thus, the L/V data presented is a conservative estimate of vehicle performance.

The performance in the tangent track test zones was good, with vertical, lateral, and roll performance well below Chapter XI criteria. This general result was matched by the model, with the details of the vertical and roll resonant frequencies being different due to the incorrect simulation of the leaf spring friction damping.

The performance in the curved test zones was as would be expected for a vehicle with a rigid truck frame. This prevents the axles from steering effectively into the curves, causing relatively high lateral forces and hence increased L/V ratios. These wheel/rail forces and L/V ratios were however not very different from those generated by normal freight cars with three-piece trucks. Thus performance for the locomotive is acceptable.

It is obvious from both model and test results that the three configurations showed no significant differences in safety performance for any of the test conditions. It can therefore be concluded that adding a crash structure up to 20,000 pounds of weight to the cab should not decrease the safety performance of this type of locomotive.

These analyses have not addressed whether the increased cab weight has increased the maximum wheel-on-rail lateral and vertical forces. It is possible that these maxima have increased but that the maximum L/V ratios were unaffected because the lateral and vertical forces increased proportionally. An increase in the lateral and vertical forces has no immediate impact on safety performance, but may lead to more rapid wear or degradation of the track structure over time.

Although beyond the scope of this project, the test results and model predictions should be analyzed to determine whether the maximum wheel/rail forces have been increased to a detrimental level.

8.4 INSTRUMENTED WHEEL SETS

Problems were encountered with the FRA/ASEA built instrumented wheel sets. It was decided that leasing newer wheel sets built by EMD would provide better quality data for the same cost as repairing the old wheel sets. The EMD wheel sets proved to be very reliable and consistent, and although they did have some shortcomings with regard to accuracy, it is believed that they are more accurate than the FRA/ASEA wheel sets would have been.

For future locomotive tests, it is recommended that the current FRA/ASEA wheel sets be abandoned. New wheel sets should be purchased for future tests or else the currently available wheel sets should be leased. New design techniques for instrumented wheel sets should provide more reliable results with much greater accuracy than even the current EMD instrumented wheel sets.

9.0 SUMMARY

In summary, it appears that the safety performance of EMD type 4-axle locomotives is not adversely affected by the increased weight (up to 20,000 lb) due to a crash structure in a locomotive cab.

A NUCARS model of the locomotive has been developed. This requires some modification to the simulation of leaf spring friction to correctly simulate vertical and roll resonant behavior.

A follow up research program is recommended. The data from this test program should be analyzed to determine whether the increased cab loads cause increased maximum loads on the track structure which could cause more rapid track degradation and wear. In addition, the corrections should be made to the NUCARS model of the leaf spring friction. Then the validation of the model should be completed relative to the test results.

With the NUCARS model of the locomotive validated, the model can be used to simulate different crash cab configurations as recommended by the LCCC. Other types of EMD 4-axle locomotives could also be simulated by with minor variations to the model.

REFERENCES

1. Wilson, N.G., F.D. Irani, C.L. Urban, "Safety Aspects of New and Untried Freight Cars," Federal Railroad Administration Final Report, DOT/FRA/ORD-88/07, November 1989.
2. Wilson, Nicholas G., "Safety Aspects of New Trucks and Lightweight Cars, Car 2," Federal Railroad Administration Final Report, DOT/FRA/ORD-92/04, April 1992.
3. Wilson, Nicholas G., "Extended NUCARS Safety Assessment," Federal Railroad Administration Final Report," DOT/FRA/ORD-92/30, June 1992.
4. Otter, Duane E., Magdy A. El-Sibaie, Richard L. Higgins, "A Design for Next Generation Load Measuring Wheel Sets," *Proceedings*, presented at IEEE/ASME Joint Railroad Conference, St. Louis, Missouri, May 21-23, 1991.
5. Elkins, J.A., P.E. Klauser, F.B. Blader, "Applications Using NUCARS: A General Purpose Rail Vehicle Dynamics Simulation," *Proceedings*, presented at COMPRAIL 90, International Conference, Rome, Italy, March 1990.

APPENDIX A

INSTRUMENTATION DATA CHANNEL REQUIREMENTS

LOCOMOTIVE HEAVY AXLE LOAD TESTS, VEHICLE CHARACTERIZATION TESTS

INSTRUMENTATION DATA CHANNEL REQUIREMENTS - page 1 of 3				
Project Name:	Locomotive Heavy Axle Load Tests, Vehicle Characterization Tests			
Work Order:	A1B700			
Test Engineer:	Nicholas WIlson			
NAME	LOCATION AND DESCRIPTION	SIGN CONVENTION	TYPE	RANGE
VAD1	Left Side Vertical Actuator Displacement	Negative for extension	LVDT	+/-5 in.
VAD2	Right Side Vertical Actuator Displacement	Negative for extension	LVDT	+/-5 in.
LAD1	Left Side Lateral Actuator Displacement	Positive for extension	LVDT	+/-5 in.
VAF1	Left Side Vertical Actuator Force	Negative for extension	Load Cell	+/-25 kips
VAF2	Right Side Vertical Actuator Force	Negative for extension	Load Cell	+/-25 kips
LAF1	Left Side Lateral Actuator Force	Positive for extension	Load Cell	+/-10 kips
VLF1	Left Side Lead Axle Vertical Rail Force	Positive for Weighing Vehicle	Load Cell	
VRF1	Right Side Lead Axle Vertical Rail Force	Positive for Weighing Vehicle	Load Cell	
VLF2	Left Side Trail Axle Vertical Rail Force	Positive for Weighing Vehicle	Load Cell	
VRF2	Right Side Trail Axle Vertical Rail Force	Positive for Weighing Vehicle	Load Cell	
LLF1	Left Side Lead Axle Lateral Rail Force	Positive when vehicle is pulled to the left	Load Cell	
LRF1	Right Side Lead Axle Lateral Rail Force	Negative when vehicle is pushed to the right	Load Cell	
LLF2	Left Side Trail Axle Lateral Rail Force	Positive when vehicle is pulled to the left	Load Cell	
LRF2	Right Side Trail Axle Lateral Rail Force	Negative when vehicle is pushed to the right	Load Cell	
DY1	Lead Axle Left Side Primary Lateral Spring Displacement Between Axle and Truck Frame	Positive when vehicle is pulled to the left	LVDT	+/-1 in.

INSTRUMENTATION DATA CHANNEL REQUIREMENTS - page 2 of 3				
Project Name: Locomotive Heavy Axle Load Tests, Vehicle Characterization Tests Work Order: A1B700 Test Engineer: Nicholas WIlson				
DY2	Trail Axle Left Side Primary Lateral Spring Displacement Between Axle and Truck Frame	Positive when vehicle is pulled to the left	LVDT	+/-1 in.
DY3	Secondary Lateral Spring Displacement Between Truck Frame and Bolster	Positive when vehicle is pulled to the left	LVDT	+/-1 in.
DZ1	Lead Axle Left Side Primary Vertical Spring Displacement Between Axle and Truck Frame	Negative for compressing the springs	String Pot	+/-5 in.
DZ2	Lead Axle Right Side Primary Vertical Spring Displacement Between Axle and Truck Frame	Negative for compressing the springs	String Pot	+/-5 in.
DZ3	Trail Axle Left Side Primary Vertical Spring Displacement Between Axle and Truck Frame	Negative for compressing the springs	String Pot	+/-5 in.
DZ4	Trail Axle Right Side Primary Vertical Spring Displacement Between Axle and Truck Frame	Negative for compressing the springs	String Pot	+/-5 in.
DZ5	Left Side Secondary Vertical Spring Displacement Between Truck Frame (Spring Plank) and Bolster	Negative for compressing the springs	String Pot	+/-5 in.
DZ6	Right Side Secondary Vertical Spring Displacement Between Truck Frame (Spring Plank) and Bolster	Negative for compressing the springs	String Pot	+/-5 in.
DZ7	Left Side Bolster to Body Displacement Across Sidebearings	Negative for closing the gap	String Pot	+/-5 in.
DZ8	Right Side Bolster to Body Displacement Across Sidebearings	Negative for closing the gap	String Pot	+/-5 in.
AY1	Left Side Sill at Lead Bolster Lateral Acceleration	Positive for body motion to the left	Accel	+/-2 g.
AY2	Left Side Sill at Lead End Steps Lateral Acceleration	Positive for body motion to the left	Accel	+/-2 g.
AY3	Left Side Sill at Center of Body Lateral Acceleration	Positive for body motion to the left	Accel	+/-2 g.
AY4	Left Side Sill at Trail End Steps Lateral Acceleration	Positive for body motion to the left	Accel	+/-2 g.
AY5	Right Side Sill at Lead End Steps Lateral Acceleration	Positive for body motion to the left	Accel	+/-2 g.

INSTRUMENTATION DATA CHANNEL REQUIREMENTS - page 3 of 3				
Project Name: Locomotive Heavy Axle Load Tests, Vehicle Characterization Tests Work Order: A1B700 Test Engineer: Nicholas WIlson				
AY6	Left Side Sill at Trail End Steps Lateral Acceleration	Positive for body motion to the left	Accel	+/-2 g.
AZ1	Left Side Sill at Lead Bolster Vertical Acceleration	Positive for upward body motion	Accel	+/-2 g.
AZ2	Left Side Sill at Lead End Steps Vertical Acceleration	Positive for upward body motion	Accel	+/-2 g.
AZ3	Left Side Sill at Center of Body Vertical Acceleration	Positive for upward body motion	Accel	+/-2 g.
AZ4	Left Side Sill at Trail End Steps Vertical Acceleration	Positive for upward body motion	Accel	+/-2 g.
AZ5	Right Side Sill at Lead End Steps Vertical Acceleration	Positive for upward body motion	Accel	+/-2 g.
AZ6	Left Side Sill at Trail End Steps Vertical Acceleration	Positive for upward body motion	Accel	+/-2 g.

The sign convention for all transducers has been chosen to be compatible with a normal right handed convention. Standing in the locomotive cab facing forward, the x-axis will be positive straight ahead, the y-axis will be positive to the left side of the locomotive, the z-axis will be positive straight up. This sign convention has been chosen to be compatible with the NUCARS computer model. A check of all transducers for their sign shall be made before testing commences.

APPENDIX B

INSTRUMENTATION DATA CHANNEL REQUIREMENTS
LOCOMOTIVE HEAVY AXLE LOAD TESTS, ON-TRACK TESTS

INSTRUMENTATION DATA CHANNEL REQUIREMENTS - page 1 of 3				
Project Name: Locomotive Heavy Axle Load Tests, On-Track Tests Work Order: A1B700 Test Engineer: Nicholas WIlson				
NAME	LOCATION AND DESCRIPTION	SIGN CONVENTION	TYPE	RANGE
LL1	Axle 1 Left Wheel Lateral Load	Positive for Flanging Force	Instrumented Wheel Set	+/-50 Kips
LR1	Axle 1 Right Wheel Lateral Load	Positive for Flanging Force	Instrumented Wheel Set	+/-50 Kips
LL2	Axle 2 Left Wheel Lateral Load	Positive for Flanging Force	Instrumented Wheel Set	+/-50 Kips
LR2	Axle 2 Right Wheel Lateral Load	Positive for Weighing Vehicle	Instrumented Wheel Set	+/-50 Kips
VL1	Axle 1 Left Wheel Vertical Load	Positive for Weighing Vehicle	Instrumented Wheel Set	0-100 Kips
VR1	Axle 1 Right Wheel Vertical Load	Positive for Weighing Vehicle	Instrumented Wheel Set	0-100 Kips
VL2	Axle 2 Left Wheel Vertical Load	Positive for Weighing Vehicle	Instrumented Wheel Set	0-100 Kips
VR2	Axle 2 Right Wheel Vertical Load	Positive for Weighing Vehicle	Instrumented Wheel Set	0-100 Kips
LVL1	Axle 1 Left Wheel L/V Ratio	Positive for Flanging Force	Instrumented Wheel Set	+/-2
LVR1	Axle 1 Right Wheel L/V Ratio	Positive for Flanging Force	Instrumented Wheel Set	+/-2
LVL2	Axle 2 Left Wheel L/V Ratio	Positive for Flanging Force	Instrumented Wheel Set	+/-2
LVR2	Axle 2 Right Wheel L/V Ratio	Positive for Flanging Force	Instrumented Wheel Set	+/-2
TRQ1	Axle 1 Torque Bridge	Postive for Right Wheel Twisting Clockwise Relative to Left Wheel	Instrumented Wheel Set	
TRQ2	Axle 2 Torque Bridge	Postive for Right Wheel Twisting Clockwise Relative to Left Wheel	Instrumented Wheel Set	
DX1	Left Side Longitudinal Displacement Between Truck Frame and Body	Positive when Truck Rotates Counter-Clockwise	String Pot	+/-5 in.
DX2	Right Side Longitudinal Displacement Between Truck Frame and Body	Positive when Truck Rotates Counter-Clockwise	String Pot	+/-5 in.

INSTRUMENTATION DATA CHANNEL REQUIREMENTS - page 2 of 3				
Project Name: Locomotive Heavy Axle Load Tests, On-Track Tests Work Order: A1B700 Test Engineer: Nicholas WIlson				
DY1	Secondary Lateral Spring Displacement Between Truck Frame and Bolster	Positive when Vehicle is Pulled to the Left	String Pot	+/-2 in.
DZ1	Axle 1 Left Side Primary Vertical Spring Displacement Between Axle and Lead Truck Frame	Negative for Compressing the Springs	String Pot	+/-5 in.
DZ2	Axle 1 Right Side Primary Vertical Spring Displacement Between Axle and Lead Truck Frame	Negative for Compressing the Springs	String Pot	+/-5 in.
DZ3	Axle 2 Left Side Primary Vertical Spring Displacement Between Axle and Lead Truck Frame	Negative for Compressing the Springs	String Pot	+/-5 in.
DZ4	Axle 2 Right Side Primary Vertical Spring Displacement Between Axle and Lead Truck Frame	Negative for Compressing the Springs	String Pot	+/-5 in.
DZ5	Left Side Secondary Vertical Spring Displacement Between Lead Truck Frame (Spring Plank) and Bolster	Negative for Compressing the Springs	String Pot	+/-5 in.
DZ6	Right Side Secondary Vertical Spring Displacement Between Lead Truck Frame (Spring Plank) and Bolster	Negative for Compressing the Springs	String Pot	+/-5 in.
AY1	Left Side Sill at Lead Bolster Lateral Acceleration	Positive for Body Motion to the Left	Accel	+/-5 g.
AY2	Left Side Sill at Trail Bolster Lateral Acceleration	Positive for Body Motion to the Left	Accel	+/-5 g.
AY3	Axle 1 Lateral Acceleration	Positive for Body Motion to the Left	Accel	+/-10 g.
AY4	Axle 2 Lateral Acceleration	Positive for Body Motion to the Left	Accel	+/-10 g.
AY5	Axle 3 Lateral Acceleration	Positive for Body Motion to the Left	Accel	+/-10 g.
AY6	Axle 4 Lateral Acceleration	Positive for Body Motion to the Left	Accel	+/-10 g.
RG1	Roll Gyro on Lead Platform	Postive for Right Wheel Twisting Clockwise Relative to Left Wheel	Roll Gyro	

INSTRUMENTATION DATA CHANNEL REQUIREMENTS - page 3 of 3				
Project Name: Locomotive Heavy Axle Load Tests, On-Track Tests Work Order: A1B700 Test Engineer: Nicholas WIlson				
RG2	Roll Gyro on Trail Platform	Postive for Right Wheel Twisting Clockwise Relative to Left Wheel	Roll Gyro	
TSPD	Train Speed	Positive for Forward Motion	Speedometer	0-100mph

The sign convention for all transducers has been chosen to be compatible with a normal right handed convention. Standing in the locomotive cab facing forward, the x-axis will be positive straight ahead, the y-axis will be positive to the left side of the locomotive, the z-axis will be positive straight up. This sign convention has been chosen to be compatible with the NUCARS computer model. A check of all transducers for their sign shall be made before testing commences.

APPENDIX C

NUCARS SYSTEM FILES FOR LOCOMOTIVE CONFIGURATIONS 1, 2, AND 3

Table C1. Locomotive Configuration 1

```
System file (.SYS) for NUCARS Version 2.0
=======================================
\SYSTEM TITLE
4 Axle GP35 Loco, w/high speed mods, Config. 1, w/soft primary springs
Give the number of bodies, then for each, list the number, name, up to 15
characters in single quotes, and c.g. position, relative to a chosen datum,
followed by the number and list of degrees of freedom required (from 1=x,
2=y, 3=z, 4=phi, 5=theta, 6=psi, 7=epsx, 8=epsy, 9=epsz), and the mass and
inertias in roll, pitch, and yaw.  The degrees of freedom required for each
axle are 2, 3, 4, and 6.
 Body # ' 15 Char Name  '          C.G. Posn in X, Y, & Z
        No. & DoF List             Mass, Roll, Pitch, & Yaw Inertia
---------------------------------------------------------------------
\BODY DATA
  13
   1     ' Loco Main Body'       -243.64      0.0       82.465
        7   2 3 4 5 6 7 8        453.85     6.34e5     1.0375E7  1.0215E7
   2     'Leading Bolster'        -54.0       0.0       40.0
        5   2 3 4 5 6              5.32     3.6E3      0.4E4     3.6E3
   3     'Trailng Bolster'       -440.0       0.0       40.0
        5   2 3 4 5 6              5.32     3.6E3      0.4E4     3.6E3
   4     'Lead Truck Frm '        -54.0       0.0       28.6
        5   2 3 4 5 6             47.0      3.1E4      9.7E4     7.7E4
   5     'Trail Truck Frm'       -440.0       0.0       28.6
        5   2 3 4 5 6             47.0      3.1E4      9.7E4     7.7E4
   6     ' Tract Motor 1 '        -14.0       0.0       20.0
        2   3 5                   15.54     3.24E3     2.33E3    3.24E3
   7     ' Tract Motor 2 '        -94.0       0.0       20.0
        2   3 5                   15.54     3.24E3     2.33E3    3.24E3
   8     ' Tract Motor 3 '       -400.0       0.0       20.0
        2   3 5                   15.54     3.24E3     2.33E3    3.24E3
   9     ' Tract Motor 4 '       -480.0       0.0       20.0
        2   3 5                   15.54     3.24E3     2.33E3    3.24E3
  10     ' Axle Number 1 '          0.0       0.0       20.0
        4   2 3 4 6                8.69     1.06E4     1.67E3    1.18E4
  11     ' Axle Number 2 '       -108.0       0.0       20.0
        4   2 3 4 6                8.69     1.06E4     1.67E3    1.18E4
  12     ' Axle Number 3 '       -386.0       0.0       20.0
        4   2 3 4 6                8.69     1.06E4     1.67E3    1.18E4
  13     ' Axle Number 4 '       -494.0       0.0       20.0
        4   2 3 4 6                8.69     1.06E4     1.67E3    1.18E4
For all bodies with flexible modes, give the position of each body
geometric center, in the X direction from the datum, its length, and
the natural frequencies (Hz) and damping ratios in twist, vertical,
and lateral bending.
  Body #     X-Posn    X-Length   Nat Frequencies     Damping Ratios
---------------------------------------------------------------------
\FLEXIBLE MODES
   1        -247.0      600.0      5.5   6.34   30.0    0.013  0.047   0.02
Give the number of connections, then for each, identify a name, in single
quotes and of up to 20 characters, a position relative to the chosen datum,
numbers for the bodies at each end, 0 for an earth in local track coords.,
a number indicating the degree of freedom, translational 1,2,3 or rotational
4,5,6, in x,y,z resp., including 2 for lateral wheel motion, and the type:
    1 - parallel pair of spring and damper characteristics
    2 - series pair of spring and damper characteristics
    3 - device with hysteresis between 2 PWL characteristics, e.g. carriage
        spring or load sensitive suspension
    4 - lateral/longitudinal suspension of the wheel on rail
    5 - connection force as a history of the distance moved
and the identification number for each of type 1, 2 and 3, the axle number
for type 4, input function number for type 5.
Note - single characteristics are treated as parallel pairs with the
       missing characteristic set to zero in the subsequent table.
```

```
Conn # ' 20 CHARACTER NAME  ' Type Body 1 & 2  Posn in X, Y, & Z   DoF No.
-----------------------------------------------------------------------
\CONNECTION DATA
 66
  1    ' Carbody-L.Bol Y-sup'  1   1   2     -54.0   0.0  40.0       2   1
  2    ' Carbody-T.Bol Y-sup'  1   1   3    -440.0   0.0  40.0       2   1
  3    'L.Bol-Truk framY-sup'  1   2   4     -54.0   0.0  25.0       2   11
  4    'T.Bol-Truk framY-sup'  1   3   5    -440.0   0.0  25.0       2   11
  5    ' Ax 1-Truck Frame Y '  1   4   10      0.0   0.0  28.0       2   2
  6    ' Ax 2-Truck Frame Y '  1   4   11   -108.0   0.0  28.0       2   2
  7    ' Ax 3-Truck Frame Y '  1   5   12   -386.0   0.0  28.0       2   2
  8    ' Ax 4-Truck Frame Y '  1   5   13   -494.0   0.0  28.0       2   2
  9    ' Carbody-L.Bol L Z-s'  1   1   2     -54.0  10.0  43.0       3   3
 10    ' Carbody-L.Bol R Z-s'  1   1   2     -54.0 -10.0  43.0       3   3
 11    ' Carbody-L.Bol F Z-s'  1   1   2     -44.0   0.0  43.0       3   3
 12    ' Carbody-L.Bol B Z-s'  1   1   2     -64.0   0.0  43.0       3   3
 13    ' Carbody-L.Bolst Yaw'  2.1 1   2     -54.0   0.0  43.0       6   4
 14    'L.Bol-Truck Lt Z-sup'  3   2   4     -54.0  38.0  28.0       3   14
 15    'L.Bol-Truck Rt Z-sup'  3   2   4     -54.0 -38.0  28.0       3   14
 16    'L.Bol-Truk Yaw suspn'  1   2   4     -54.0   0.0  28.0       6   9
 17    'L.Bol-Truk Pitch spn'  1   2   4     -54.0   0.0  28.0       5   8
 18    ' Carbody-T.Bol R Z-s'  1   1   3    -440.0 -10.0  43.0       3   3
 19    ' Carbody-T.Bol L Z-s'  1   1   3    -440.0  10.0  43.0       3   3
 20    ' Carbody-T.Bol F Z-s'  1   1   3    -430.0   0.0  43.0       3   3
 21    ' Carbody-T.Bol B Z-s'  1   1   3    -450.0   0.0  43.0       3   3
 22    ' Carbody-T.Bolst Yaw'  2.1 1   3    -440.0   0.0  43.0       6   4
 23    'T.Bol-Truck Lt Z-sup'  3   3   5    -440.0  38.0  28.0       3   14
 24    'T.Bol-Truck Rt Z-sup'  3   3   5    -440.0 -38.0  28.0       3   14
 25    'T.Bol-Truk Yaw suspn'  1   3   5    -440.0  0.0   28.0       6   9
 26    'T.Bol-Truk Pitch spn'  1   3   5    -440.0   0.0  28.0       5   8
 27    'Ax 1-Lead Truck Lt Z'  1   4   10      0.0  39.5  35.0       3   5
 28    'Ax 1-Lead Truck Rt Z'  1   4   10      0.0 -39.5  35.0       3   5
 29    'Ax 1-Truk Yaw suspen'  1   4   10      0.0   0.0  28.0       6   6
 30    'Ax 2-Lead Truck Lt Z'  1   4   11   -108.0  39.5  35.0       3   5
 31    'Ax 2-Lead Truck Rt Z'  1   4   11   -108.0 -39.5  35.0       3   5
 32    'Ax 2-Truk Yaw suspen'  1   4   11   -108.0   0.0  28.0       6   6
 33    'Ax 3-Tral Truck Lt Z'  1   5   12   -386.0  39.5  35.0       3   5
 34    'Ax 3-Tral Truck Rt Z'  1   5   12   -386.0 -39.5  35.0       3   5
 35    'Ax 3-Truk Yaw suspen'  1   5   12   -386.0   0.0  28.0       6   6
 36    'Ax 4-Tral Truck Lt Z'  1   5   13   -494.0  39.5  35.0       3   5
 37    'Ax 4-Tral Truck Rt Z'  1   5   13   -494.0 -39.5  35.0       3   5
 38    'Ax 4-Truk Yaw suspen'  1   5   13   -494.0   0.0  28.0       6   6
 39   'Ax 1 Lt Whl/Rail Lat'   4   10          0.0    29.75     0.0  1
 40   'Ax 1 Rt Whl/Rail Lat'   4   10          0.0   -29.75     0.0  1
 41   'Ax 2 Lt Whl/Rail Lat'   4   11       -108.0    29.75     0.0  2
 42   'Ax 2 Rt Whl/Rail Lat'   4   11       -108.0   -29.75     0.0  2
 43   'Ax 3 Lt Whl/Rail Lat'   4   12       -386.0    29.75     0.0  3
 44   'Ax 3 Rt Whl/Rail Lat'   4   12       -386.0   -29.75     0.0  3
 45   'Ax 4 Lt Whl/Rail Lat'   4   13       -494.0    29.75     0.0  4
 46   'Ax 4 Rt Whl/Rail Lat'   4   13       -494.0   -29.75     0.0  4
 47    ' Ax 1 / Tn Mtr Vert '  1   6   10      0.0   0.0  20.0       3   13
 48    ' Ax 2 / Tn Mtr Vert '  1   7   11   -108.0   0.0  20.0       3   13
 49    ' Ax 3 / Tn Mtr Vert '  1   8   12   -386.0   0.0  20.0       3   13
 50    ' Ax 4 / Tn Mtr Vert '  1   9   13   -494.0   0.0  20.0       3   13
 51    ' Tn Mtr 1 / Trk Vert'  1   6   4     -29.0   0.0  20.0       3   10
 52    ' Tn Mtr 2 / Trk Vert'  1   7   4     -79.0   0.0  20.0       3   10
 53    ' Tn Mtr 3 / Trk Vert'  1   8   5    -415.0   0.0  20.0       3   10
 54    ' Tn Mtr 4 / Trk Vert'  1   9   5    -465.0   0.0  20.0       3   10
 55    ' Lft Side Bearing 1 '  1   1   2     -54.0  26.5  43.0       3   12
 56    ' Rgt Side Bearing 1 '  1   1   2     -54.0 -26.5  43.0       3   12
 57    ' Lft Side Bearing 2 '  1   1   3    -440.0  26.5  43.0       3   12
 58    ' Rgt Side Bearing 2 '  1   1   3    -440.0 -26.5  43.0       3   12
 59    'Ax 1 Rt Vert Damper '  2   4   10      0.0 -39.5  35.0       3   15
 60    'Ax 2 Lt Vert Damper '  2   4   11   -108.0  39.5  35.0       3   15
 61    'Ax 3 Rt Vert Damper '  2   5   12   -386.0 -39.5  35.0       3   15
 62    'Ax 4 Lt Vert Damper '  2   5   13   -494.0  39.5  35.0       3   15
 63    'L.Bol-Truk Lat Damp '  2   2   4     -54.0   0.0  12.0       2   16
 64    'T.Bol-Truk Lat Damp '  2   3   5    -440.0   0.0  12.0       2   16
 65    'Body-Trck 1 Yaw Damp'  2   1   4     -54.0   0.0  43.0       6   17
 66    'Body-Trck 2 yaw Damp'  2   1   5    -440.0   0.0  43.0       6   17
```

```
For each type 1 - parallel connection, list its number, followed by
the identification numbers of the piecewise linear characteristics
for the stiffness and damping, respectively, zero if absent, and the
the combined force or moment limit in extn and compn, lb or in-lb
(if no limit exists, set the F-values outside the expected range).
     Pair #     Stiff PWL    Damp PWL      F-extn.      F-compn.
---------------------------------------------------------------------------
For each type 2 - series connection, list its number, followed by
the identification numbers of the piecewise linear characteristics
for the stiffness and damping, respectively, and the stroke limit
in extension and compression for the pair, inches or rad, and the
stiffness of the stop at the limit in lb/in or in-lb/rad (if no
limit exists, set the S-values outside the expected range).
     Pair #     Stiff PWL   Damp PWL    S-extn.     S-compn.   Stop K
---------------------------------------------------------------------------
For each type 2.1 - series friction connection, list its number, followed by
the identification numbers of the piecewise linear characteristics
for the friction, and the stroke limit
in extension and compression for the pair, inches or rad, and the
stiffness of the stop at the limit in lb/in or in-lb/rad (if no
limit exists, set the S-values outside the expected range), and the linear
stiffness and linear damping in series with the friction.
     Pair #   Damp PWL   S-extn. S-compn. Stop K  Series Stiff. Series Damp.
---------------------------------------------------------------------------
For each type 3 - hysteresis loop characteristic, list its number,
followed by identification numbers for the extension and compression
piecewise linear charateristics, extension and compression force limits,
and a linear viscous damping in lb-sec/in or in-lb-sec/rad.
     Loop #      Extn PWL   Comp PWL    F-extn.  F-compn.   LVB Damping
---------------------------------------------------------------------------
\CHARACTERISTIC DATA
        1         1           2           1.0E08      -1.0E08
        2         3           4           1.0E08      -1.0E08
        3         5           6           0.0E08      -1.0E08
        4         7      1.0     -1.0     1.0e9   1.0e9    1.0e6
        5         8           9           0.0E08      -1.0E08
        6        10          11           1.0E08      -1.0E08
        8        23          24           1.0E08      -1.0E08
        9        16          17           1.0E08      -1.0E08
       10        18          19           1.0E08      -1.0E08
       11        20          21           1.0E08      -1.0E08
       12        22           0           1.0E08      -1.0E08
       13        25          26           1.0E08      -1.0E08
       14        14          15           1.0E08   -1.0E08       4.5E6
       15        27          28           0.1         -5.6       1.0e6
       16        29          30           2.1         -2.1       1.0e6
       17        31          32           0.08        -0.08      1.0e9
For each type 4 - axle to track characteristic, list an identification
number, WRAD, the nominal wheel radius,
INDWH, a wheel rotation index, .F. for solid, .T. for independent wheels,
ITRQ, traction torque input nos. for left and right wheels, 0 for none,
and, for independent wheels, KWHL, DWHL, the axle torsional stiffness
and damping.
   Axle #     WRAD     INDWH      ITRQ-L     ITRQ-R     KWHL     DWHL
---------------------------------------------------------------------------
\WHEEL/RAIL ELEMENT
    4.E5     4.E3      12   13
     1        20.0      .F.         0          0        0.0      0.0
     2        20.0      .F.         0          0        0.0      0.0
     3        20.0      .F.         0          0        0.0      0.0
     4        20.0      .F.         0          0        0.0      0.0
List the data required for each piecewise linear function, the PWL
number, the number of break points in each PWL, and ordinate, lb or
in-lb, over abscissa, inches or rad, at each break point.
Note - extension is assumed to be positive for both ordinate and abscissa
       and 0.0 for the first break point indicates symmetry about the origin
   PWL     IBP     Ordinates over Abscissae
---------------------------------------------------------------------------
\PWL DATA
  1        2    -1.00E06     1.00E06                     (locom-bolster lat stiff. )
                -1.0         1.0
  2        2    -1.00E03     1.00E03                     (locom-bolster lat damping)
                -1.0         1.0
```

```
  3     4    0.0    600.0    6.85E03    1.0685E05     (primary  -lateral stiff. )
             0.0     0.05    0.1         0.2
  4     3    0.0            1.2E03     1.2E03         (primary  -lateral damping)
             0.0            0.06       1.0
  5     2   -1.00E06        1.00E06               (locom-bolster C.P. vert stiff.)
            -1.0            1.0
  6     2   -1.00E03        1.00E03               (locom-bolster C.P. vert damp. )
            -1.0            1.0
  7     3    0.0            5.77E03    5.77E03      (center plate yaw friction)
             0.0            0.1        1.0
  8     4   -1.451E05  -4.51E04     0.0       0.0  (soft primary-vertical stiff.)
            -5.6       -5.5         0.0       1.0
  9     3    0.00           0.655E03   0.655E03     (soft primary-vert.frictin damp)
             0.0            0.033      1.0
 10     5    0.0  4.15e4  2.78e5    9.1e6    7.98e7  (primary  -yaw stiffness  )
             0.0  0.0023  0.0031    0.0039   0.0293
 11     2   -1.60E05        1.60E05                 (primary  -yaw damping    )
            -1.0            1.0
 12     2    0.0            1.00E05                 (track    -vertical stiff. )
             0.0            1.0
 13     2    0.0            1.00E03                 (track    -vertical damp.  )
             0.0            1.0
 14   7  -2.02E05 -1.02E05 -8.67E04 -4.32E04 -3.27E04 -2.36E04 0.0 (Scdry Vert)
         -4.55    -4.45    -4.3     -2.5     -2.3     -1.7     0.0
 15   6  -2.24E05 -1.24E05 -7.32E04 -5.22E04 -4.17E04 -2.4E04      (Scdry Vrt)
         -4.55    -4.45    -3.0     -2.1     -1.7      0.0
 16     2   -1.0E09         1.0E9                   (Bolster to Truck Yaw Stiff)
            -1.0            1.0
 17     2   -1.0E06         1.0E06                  (Bolster to truck Yaw Damp)
            -1.0            1.0
 18     2    0.0            1.754E04                (Tn motor to truck stiffness )
             0.0            1.0
 19     2   -1.0E02         1.0E02                  (Tn motor to Truck damping   )
            -1.0            1.0
 20     3    0.0            1.4E04     2.14E05      (sec. lat-bolst truck stiffness)
             0.0            2.0        2.1
 21     3    0.0            9.08E03    9.08E03      (sec. lat-bolst truck damping  )
             0.0            0.1135     1.0
 22     4   -1.0E06         0.0        0.0       1.0E06       (side bearings)
            -1.25          -0.25       0.0       0.25
 23     2    0.0            1.0e8                   (Bolster/Truck Pitch Stiff)
             0.0            1.0
 24     2    0.0            1.0e5                   (Bolster/Truck Pitch Damp)
             0.0            1.0
 25     2   -1.00E06        1.00E06                 (Axle/Tn. Motor Vert stiff. )
            -1.0            1.0
 26     2   -1.00E03        1.00E03                 (Axle/Tn. Motor vert damping)
            -1.0            1.0
 27     2    0.0            3702.0                  (Vert Damper Bushing stiff. )
             0.0            1.0
 28     2    0.0            530.0                   (Vert Damper Damping)
             0.0            1.0
 29     2    0.0            7940.0                  (Lat Damper Bushing stiff. )
             0.0            1.0
 30     2    0.0            400.0                   (Lat Damper Damping)
             0.0            1.0
 31     2   -4.7e7          4.7e7                   (Yaw Damper Bushing stiff. )
            -1.0            1.0
 32     3    0.0            1.98e5     2.01e5       (Yaw Damper Damping)
             0.0            0.0119     0.0253
```

Table C2. Locomotive Configuration 2

```
System file (.SYS) for NUCARS Version 2.0
========================================
\SYSTEM TITLE
4 Axle GP35, w/high speed mods, Config 2, 20klb cab load, w/soft primary springs
Give the number of bodies, then for each, list the number, name, up to 15
characters in single quotes, and c.g. position, relative to a chosen datum,
followed by the number and list of degrees of freedom required (from 1=x,
2=y, 3=z, 4=phi, 5=theta, 6=psi, 7=epsx, 8=epsy, 9=epsz), and the mass and
inertias in roll, pitch, and yaw.  The degrees of freedom required for each
axle are 2, 3, 4, and 6.
 Body #  ' 15 Char Name  '           C.G. Posn in X, Y, & Z
          No. & DoF List             Mass, Roll, Pitch, & Yaw Inertia
-------------------------------------------------------------------------
\BODY DATA
  13
   1      ' Loco Main Body'       -225.08      0.0       84.51
       7   2 3 4 5 6 7 8          506.9      7.70e5     1.222E7    1.216E7
   2      'Leading Bolster'        -54.0       0.0       40.0
       5   2 3 4 5 6                5.32     3.6E3      0.4E4      3.6E3
   3      'Trailng Bolster'       -440.0       0.0       40.0
       5   2 3 4 5 6                5.32     3.6E3      0.4E4      3.6E3
   4      'Lead Truck Frm '        -54.0       0.0       28.6
       5   2 3 4 5 6               47.0      3.1E4      9.7E4      7.7E4
   5      'Trail Truck Frm'       -440.0       0.0       28.6
       5   2 3 4 5 6               47.0      3.1E4      9.7E4      7.7E4
   6      ' Tract Motor 1 '        -14.0       0.0       20.0
       2   3 5                     15.54     3.24E3     2.33E3     3.24E3
   7      ' Tract Motor 2 '        -94.0       0.0       20.0
       2   3 5                     15.54     3.24E3     2.33E3     3.24E3
   8      ' Tract Motor 3 '       -400.0       0.0       20.0
       2   3 5                     15.54     3.24E3     2.33E3     3.24E3
   9      ' Tract Motor 4 '       -480.0       0.0       20.0
       2   3 5                     15.54     3.24E3     2.33E3     3.24E3
  10      ' Axle Number 1 '          0.0       0.0       20.0
       4   2 3 4 6                  8.69     1.06E4     1.67E3     1.18E4
  11      ' Axle Number 2 '       -108.0       0.0       20.0
       4   2 3 4 6                  8.69     1.06E4     1.67E3     1.18E4
  12      ' Axle Number 3 '       -386.0       0.0       20.0
       4   2 3 4 6                  8.69     1.06E4     1.67E3     1.18E4
  13      ' Axle Number 4 '       -494.0       0.0       20.0
       4   2 3 4 6                  8.69     1.06E4     1.67E3     1.18E4
For all bodies with flexible modes, give the position of each body
geometric center, in the X direction from the datum, its length, and
the natural frequencies (Hz) and damping ratios in twist, vertical,
and lateral bending.
  Body #    X-Posn    X-Length   Nat Frequencies     Damping Ratios
-------------------------------------------------------------------------
\FLEXIBLE MODES
   1      -247.0     600.0     5.5   6.34   30.0    0.013  0.047   0.02
Give the number of connections, then for each, identify a name, in single
quotes and of up to 20 characters, a position relative to the chosen datum,
numbers for the bodies at each end, 0 for an earth in local track coords.,
a number indicating the degree of freedom, translational 1,2,3 or rotational
4,5,6, in x,y,z resp., including 2 for lateral wheel motion, and the type:
    1 - parallel pair of spring and damper characteristics
    2 - series pair of spring and damper characteristics
    3 - device with hysteresis between 2 PWL characteristics, e.g. carriage
        spring or load sensitive suspension
    4 - lateral/longitudinal suspension of the wheel on rail
    5 - connection force as a history of the distance moved
and the identification number for each of type 1, 2 and 3, the axle number
for type 4, input function number for type 5.
Note - single characteristics are treated as parallel pairs with the
       missing characteristic set to zero in the subsequent table.
```

```
Conn # ' 20 CHARACTER NAME   ' Type Body 1 & 2  Posn in X, Y, & Z   DoF No.
------------------------------------------------------------------------------
\CONNECTION DATA
 66
  1    ' Carbody-L.Bol Y-sup'  1    1   2     -54.0   0.0  40.0      2   1
  2    ' Carbody-T.Bol Y-sup'  1    1   3    -440.0   0.0  40.0      2   1
  3    'L.Bol-Truk framY-sup'  1    2   4     -54.0   0.0  25.0      2   11
  4    'T.Bol-Truk framY-sup'  1    3   5    -440.0   0.0  25.0      2   11
  5    ' Ax 1-Truck Frame Y '  1    4   10      0.0   0.0  28.0      2   2
  6    ' Ax 2-Truck Frame Y '  1    4   11   -108.0   0.0  28.0      2   2
  7    ' Ax 3-Truck Frame Y '  1    5   12   -386.0   0.0  28.0      2   2
  8    ' Ax 4-Truck Frame Y '  1    5   13   -494.0   0.0  28.0      2   2
  9    ' Carbody-L.Bol L Z-s'  1    1   2     -54.0  10.0  43.0      3   3
 10    ' Carbody-L.Bol R Z-s'  1    1   2     -54.0 -10.0  43.0      3   3
 11    ' Carbody-L.Bol F Z-s'  1    1   2     -44.0   0.0  43.0      3   3
 12    ' Carbody-L.Bol B Z-s'  1    1   2     -64.0   0.0  43.0      3   3
 13    ' Carbody-L.Bolst Yaw'  2.1  1   2     -54.0   0.0  43.0      6   4
 14    'L.Bol-Truck Lt Z-sup'  3    2   4     -54.0  38.0  28.0      3   14
 15    'L.Bol-Truck Rt Z-sup'  3    2   4     -54.0 -38.0  28.0      3   14
 16    'L.Bol-Truk Yaw suspn'  1    2   4     -54.0   0.0  28.0      6   9
 17    'L.Bol-Truk Pitch spn'  1    2   4     -54.0   0.0  28.0      5   8
 18    ' Carbody-T.Bol R Z-s'  1    1   3    -440.0 -10.0  43.0      3   3
 19    ' Carbody-T.Bol L Z-s'  1    1   3    -440.0  10.0  43.0      3   3
 20    ' Carbody-T.Bol F Z-s'  1    1   3    -430.0   0.0  43.0      3   3
 21    ' Carbody-T.Bol B Z-s'  1    1   3    -450.0   0.0  43.0      3   3
 22    ' Carbody-T.Bolst Yaw'  2.1  1   3    -440.0   0.0  43.0      6   4
 23    'T.Bol-Truck Lt Z-sup'  3    3   5    -440.0  38.0  28.0      3   14
 24    'T.Bol-Truck Rt Z-sup'  3    3   5    -440.0 -38.0  28.0      3   14
 25    'T.Bol-Truk Yaw suspn'  1    3   5    -440.0  0.0   28.0      6   9
 26    'T.Bol-Truk Pitch spn'  1    3   5    -440.0   0.0  28.0      5   8
 27    'Ax 1-Lead Truck Lt Z'  1    4   10      0.0  39.5  35.0      3   5
 28    'Ax 1-Lead Truck Rt Z'  1    4   10      0.0 -39.5  35.0      3   5
 29    'Ax 1-Truk Yaw suspen'  1    4   10      0.0   0.0  28.0      6   6
 30    'Ax 2-Lead Truck Lt Z'  1    4   11   -108.0  39.5  35.0      3   5
 31    'Ax 2-Lead Truck Rt Z'  1    4   11   -108.0 -39.5  35.0      3   5
 32    'Ax 2-Truk Yaw suspen'  1    4   11   -108.0   0.0  28.0      6   6
 33    'Ax 3-Tral Truck Lt Z'  1    5   12   -386.0  39.5  35.0      3   5
 34    'Ax 3-Tral Truck Rt Z'  1    5   12   -386.0 -39.5  35.0      3   5
 35    'Ax 3-Truk Yaw suspen'  1    5   12   -386.0   0.0  28.0      6   6
 36    'Ax 4-Tral Truck Lt Z'  1    5   13   -494.0  39.5  35.0      3   5
 37    'Ax 4-Tral Truck Rt Z'  1    5   13   -494.0 -39.5  35.0      3   5
 38    'Ax 4-Truk Yaw suspen'  1    5   13   -494.0   0.0  28.0      6   6
 39   'Ax 1 Lt Whl/Rail Lat'   4   10           0.0     29.75    0.0   1
 40   'Ax 1 Rt Whl/Rail Lat'   4   10           0.0    -29.75    0.0   1
 41   'Ax 2 Lt Whl/Rail Lat'   4   11        -108.0     29.75    0.0   2
 42   'Ax 2 Rt Whl/Rail Lat'   4   11        -108.0    -29.75    0.0   2
 43   'Ax 3 Lt Whl/Rail Lat'   4   12        -386.0     29.75    0.0   3
 44   'Ax 3 Rt Whl/Rail Lat'   4   12        -386.0    -29.75    0.0   3
 45   'Ax 4 Lt Whl/Rail Lat'   4   13        -494.0     29.75    0.0   4
 46   'Ax 4 Rt Whl/Rail Lat'   4   13        -494.0    -29.75    0.0   4
 47    ' Ax 1 / Tn Mtr Vert '  1    6   10      0.0   0.0  20.0      3   13
 48    ' Ax 2 / Tn Mtr Vert '  1    7   11   -108.0   0.0  20.0      3   13
 49    ' Ax 3 / Tn Mtr Vert '  1    8   12   -386.0   0.0  20.0      3   13
 50    ' Ax 4 / Tn Mtr Vert '  1    9   13   -494.0   0.0  20.0      3   13
 51    ' Tn Mtr 1 / Trk Vert'  1    6   4     -29.0   0.0  20.0      3   10
 52    ' Tn Mtr 2 / Trk Vert'  1    7   4     -79.0   0.0  20.0      3   10
 53    ' Tn Mtr 3 / Trk Vert'  1    8   5    -415.0   0.0  20.0      3   10
 54    ' Tn Mtr 4 / Trk Vert'  1    9   5    -465.0   0.0  20.0      3   10
 55    ' Lft Side Bearing 1 '  1    1   2     -54.0  26.5  43.0      3   12
 56    ' Rgt Side Bearing 1 '  1    1   2     -54.0 -26.5  43.0      3   12
 57    ' Lft Side Bearing 2 '  1    1   3    -440.0  26.5  43.0      3   12
 68    ' Rgt Side Bearing 2 '  1    1   3    -440.0 -26.5  43.0      3   12
 59    'Ax 1 Rt Vert Damper '  2    4   10      0.0 -39.5  35.0      3   15
 60    'Ax 2 Lt Vert Damper '  2    4   11   -108.0  39.5  35.0      3   15
 61    'Ax 3 Rt Vert Damper '  2    5   12   -386.0 -39.5  35.0      3   15
 62    'Ax 4 Lt Vert Damper '  2    5   13   -494.0  39.5  35.0      3   15
 63    'L.Bol-Truk Lat Damp '  2    2   4     -54.0   0.0  12.0      2   16
 64    'T.Bol-Truk Lat Damp '  2    3   5    -440.0   0.0  12.0      2   16
 65    'Body-Trck 1 Yaw Damp'  2    1   4     -54.0   0.0  43.0      6   17
 66    'Body-Trck 2 yaw Damp'  2    1   5    -440.0   0.0  43.0      6   17
```

```
For each type 1 - parallel connection, list its number, followed by
the identification numbers of the piecewise linear characteristics
for the stiffness and damping, respectively, zero if absent, and the
the combined force or moment limit in extn and compn, lb or in-lb
(if no limit exists, set the F-values outside the expected range).
     Pair #    Stiff PWL    Damp PWL      F-extn.     F-compn.
---------------------------------------------------------------------------
For each type 2 - series connection, list its number, followed by
the identification numbers of the piecewise linear characteristics
for the stiffness and damping, respectively, and the stroke limit
in extension and compression for the pair, inches or rad, and the
stiffness of the stop at the limit in lb/in or in-lb/rad (if no
limit exists, set the S-values outside the expected range).
     Pair #    Stiff PWL   Damp PWL    S-extn.     S-compn.   Stop K
---------------------------------------------------------------------------
For each type 2.1 - series friction connection, list its number, followed by
the identification numbers of the piecewise linear characteristics
for the friction, and the stroke limit
in extension and compression for the pair, inches or rad, and the
stiffness of the stop at the limit in lb/in or in-lb/rad (if no
limit exists, set the S-values outside the expected range), and the linear
stiffness and linear damping in series with the friction.
     Pair #   Damp PWL   S-extn. S-compn. Stop K  Series Stiff. Series Damp.
---------------------------------------------------------------------------
For each type 3 - hysteresis loop characteristic, list its number,
followed by identification numbers for the extension and compression
piecewise linear charateristics, extension and compression force limits,
and a linear viscous damping in lb-sec/in or in-lb-sec/rad.
     Loop #      Extn PWL   Comp PWL    F-extn.  F-compn.   LVB Damping
---------------------------------------------------------------------------
\CHARACTERISTIC DATA
        1        1            2           1.0E08       -1.0E08
        2        3            4           1.0E08       -1.0E08
        3        5            6           0.0E08       -1.0E08
        4        7       1.0     -1.0     1.0e9   1.0e9    1.0e6
        5        8            9           0.0E08       -1.0E08
        6       10           11           1.0E08       -1.0E08
        7       12           13           1.0E08       -1.0E08
        8       23           24           1.0E08       -1.0E08
        9       16           17           1.0E08       -1.0E08
       10       18           19           1.0E08       -1.0E08
       11       20           21           1.0E08       -1.0E08
       12       22           0            1.0E08       -1.0E08
       13       25           26           1.0E08       -1.0E08
       14       14           15           1.0E08    -1.0E08       4.5E6
       15       27           28           0.1          -5.6       1.0e6
       16       29           30           2.1          -2.1       1.0e6
       17       31           32           0.08         -0.08      1.0e9
For each type 4 - axle to track characteristic, list an identification
number, IBDAX, its general body number, WRAD, the nominal wheel radius,
INDWH, a wheel rotation index, .F. for solid, .T. for independent wheels,
ITRQ, traction torque input nos. for left and right wheels, 0 for none,
and, for independent wheels, KWHL, DWHL, the axle torsional stiffness
and damping.
   Axle #     WRAD     INDWH     ITRQ-L    ITRQ-R    KWHL     DWHL
---------------------------------------------------------------------------
\WHEEL/RAIL ELEMENT
     4.E5     4.E3    12    13
     1        20.0     .F.         0         0       0.0      0.0
     2        20.0     .F.         0         0       0.0      0.0
     3        20.0     .F.         0         0       0.0      0.0
     4        20.0     .F.         0         0       0.0      0.0
List the data required for each piecewise linear function, the PWL
number, the number of break points in each PWL, and ordinate, lb or
in-lb, over abscissa, inches or rad, at each break point.
Note - extension is assumed to be positive for both ordinate and abscissa
       and 0.0 for the first break point indicates symmetry about the origin
```

```
  PWL    IBP    Ordinates over Abscissae
-----------------------------------------------------------------------------
\PWL DATA
  1      2    -1.00E06     1.00E06                    (locom-bolster lat stiff. )
              -1.0         1.0
  2      2    -1.00E03     1.00E03                    (locom-bolster lat damping)
              -1.0         1.0
  3      4     0.0   600.0   6.85E03   1.0685E05      (primary  -lateral stiff. )
               0.0    0.05   0.1       0.2
  4      3     0.0         1.2E03    1.2E03          (primary  -lateral damping)
               0.0         0.06      1.0
  5      2    -1.00E06     1.00E06               (locom-bolster C.P. vert stiff.)
              -1.0         1.0
  6      2    -1.00E03     1.00E03               (locom-bolster C.P. vert damp. )
              -1.0         1.0
  7      3     0.0         5.77E03    5.77E03      (center plate yaw friction)
               0.0         0.1        1.0
  8      4    -1.451E05   -4.51E04    0.0      0.0  (soft primary-vertical stiff.)
              -5.6        -5.5        0.0      1.0
  9      3     0.00        0.655E03   0.655E03      (soft primary-vert.frictin damp)
               0.0         0.033      1.0
 10      5     0.0  4.15e4  2.78e5   9.1e6   7.98e7  (primary  -yaw stiffness  )
               0.0  0.0023  0.0031   0.0039  0.0293
 11      2    -1.60E05     1.60E05                    (primary  -yaw damping    )
              -1.0         1.0
 12      2     0.0         1.00E05                    (track    -vertical stiff. )
               0.0         1.0
 13      2     0.0         1.00E03                    (track    -vertical damp.  )
               0.0         1.0
 14    7  -2.02E05 -1.02E05 -8.67E04 -4.32E04 -3.27E04 -2.36E04 0.0 (Scdry Vert)
          -4.55    -4.45    -4.3     -2.5     -2.3     -1.7     0.0
 15    6  -2.24E05 -1.24E05 -7.32E04 -5.22E04 -4.17E04 -2.4E04      (Scdry Vrt)
          -4.55    -4.45    -3.0     -2.1     -1.7      0.0
 16      2    -1.0E09      1.0E9                      (Bolster to Truck Yaw Stiff)
              -1.0         1.0
 17      2    -1.0E06      1.0E06                     (Bolster to truck Yaw Damp)
              -1.0         1.0
 18      2     0.0         1.754E04                   (Tn motor to truck stiffness )
               0.0         1.0
 19      2    -1.0E02      1.0E02                     (Tn motor to Truck damping   )
              -1.0         1.0
 20      3     0.0         1.4E04     2.14E05         (sec. lat-bolst truck stiffness)
               0.0         2.0        2.1
 21      3     0.0         9.08E03    9.08E03         (sec. lat-bolst truck damping  )
               0.0         0.1135     1.0
 22      4    -1.0E06      0.0        0.0      1.0E06       (side bearings)
              -1.25       -0.25       0.0      0.25
 23      2     0.0         1.0e8                      (Bolster/Truck Pitch Stiff)
               0.0         1.0
 24      2     0.0         1.0e5                      (Bolster/Truck Pitch Damp)
               0.0         1.0
 25      2    -1.00E06     1.00E06                    (Axle/Tn. Motor Vert stiff. )
              -1.0         1.0
 26      2    -1.00E03     1.00E03                    (Axle/Tn. Motor vert damping)
              -1.0         1.0
 27      2     0.0         3702.0                     (Vert Damper Bushing stiff. )
               0.0         1.0
 28      2     0.0         530.0                      (Vert Damper Damping)
               0.0         1.0
 29      2     0.0         7940.0                     (Lat Damper Bushing stiff. )
               0.0         1.0
 30      2     0.0         400.0                      (Lat Damper Damping)
               0.0         1.0
 31      2    -4.7e7       4.7e7                      (Yaw Damper Bushing stiff. )
              -1.0         1.0
 32      3     0.0         1.98e5     2.01e5          (Yaw Damper Damping)
               0.0         0.0119     0.0253
```

Table C3. Locomotive Configuration 3

```
System file (.SYS) for NUCARS Version 2.0
========================================
\SYSTEM TITLE
4 Axle GP35, w/high speed mods, Config 3, 20klb cab load, w/stiff primary springs
Give the number of bodies, then for each, list the number, name, up to 15
characters in single quotes, and c.g. position, relative to a chosen datum,
followed by the number and list of degrees of freedom required (from 1=x,
2=y, 3=z, 4=phi, 5=theta, 6=psi, 7=epsx, 8=epsy, 9=epsz), and the mass and
inertias in roll, pitch, and yaw.  The degrees of freedom required for each
axle are 2, 3, 4, and 6.
 Body #  ' 15 Char Name  '          C.G. Posn in X, Y, & Z
           No. & DoF List           Mass, Roll, Pitch, & Yaw Inertia
------------------------------------------------------------------------
\BODY DATA
   13
    1     ' Loco Main Body'       -225.08      0.0       84.51
        7   2 3 4 5 6 7 8          506.9     7.70e5     1.222E7    1.216E7
    2     'Leading Bolster'        -54.0       0.0       40.0
        5   2 3 4 5 6               5.32     3.6E3      0.4E4      3.6E3
    3     'Trailng Bolster'       -440.0       0.0       40.0
        5   2 3 4 5 6               5.32     3.6E3      0.4E4      3.6E3
    4     'Lead Truck Frm '        -54.0       0.0       28.6
        5   2 3 4 5 6              47.0      3.1E4      9.7E4      7.7E4
    5     'Trail Truck Frm'       -440.0       0.0       28.6
        5   2 3 4 5 6              47.0      3.1E4      9.7E4      7.7E4
    6     ' Tract Motor 1 '        -14.0       0.0       20.0
        2   3 5                    15.54     3.24E3     2.33E3     3.24E3
    7     ' Tract Motor 2 '        -94.0       0.0       20.0
        2   3 5                    15.54     3.24E3     2.33E3     3.24E3
    8     ' Tract Motor 3 '       -400.0       0.0       20.0
        2   3 5                    15.54     3.24E3     2.33E3     3.24E3
    9     ' Tract Motor 4 '       -480.0       0.0       20.0
        2   3 5                    15.54     3.24E3     2.33E3     3.24E3
   10     ' Axle Number 1 '          0.0       0.0       20.0
        4   2 3 4 6                 8.69     1.06E4     1.67E3     1.18E4
   11     ' Axle Number 2 '       -108.0       0.0       20.0
        4   2 3 4 6                 8.69     1.06E4     1.67E3     1.18E4
   12     ' Axle Number 3 '       -386.0       0.0       20.0
        4   2 3 4 6                 8.69     1.06E4     1.67E3     1.18E4
   13     ' Axle Number 4 '       -494.0       0.0       20.0
        4   2 3 4 6                 8.69     1.06E4     1.67E3     1.18E4
For all bodies with flexible modes, give the position of each body
geometric center, in the X direction from the datum, its length, and
the natural frequencies (Hz) and damping ratios in twist, vertical,
and lateral bending.
  Body #     X-Posn     X-Length    Nat Frequencies      Damping Ratios
------------------------------------------------------------------------
\FLEXIBLE MODES
    1        -247.0      600.0      5.5   6.34   30.0    0.013  0.047   0.02
Give the number of connections, then for each, identify a name, in single
quotes and of up to 20 characters, a position relative to the chosen datum,
numbers for the bodies at each end, 0 for an earth in local track coords.,
a number indicating the degree of freedom, translational 1,2,3 or rotational
4,5,6, in x,y,z resp., including 2 for lateral wheel motion, and the type:
    1 - parallel pair of spring and damper characteristics
    2 - series pair of spring and damper characteristics
    3 - device with hysteresis between 2 PWL characteristics, e.g. carriage
        spring or load sensitive suspension
    4 - lateral/longitudinal suspension of the wheel on rail
    5 - connection force as a history of the distance moved
and the identification number for each of type 1, 2 and 3, the axle number
for type 4, input function number for type 5.
Note - single characteristics are treated as parallel pairs with the
       missing characteristic set to zero in the subsequent table.
```

```
Conn # ' 20 CHARACTER NAME   ' Type Body 1 & 2  Posn in X, Y, & Z   DoF No.
--------------------------------------------------------------------------
\CONNECTION DATA
  66
   1     ' Carbody-L.Bol Y-sup'  1    1   2    -54.0   0.0  40.0      2   1
   2     ' Carbody-T.Bol Y-sup'  1    1   3   -440.0   0.0  40.0      2   1
   3     'L.Bol-Truk framY-sup'  1    2   4    -54.0   0.0  25.0      2   11
   4     'T.Bol-Truk framY-sup'  1    3   5   -440.0   0.0  25.0      2   11
   5     ' Ax 1-Truck Frame Y '  1    4   10     0.0   0.0  28.0      2   2
   6     ' Ax 2-Truck Frame Y '  1    4   11  -108.0   0.0  28.0      2   2
   7     ' Ax 3-Truck Frame Y '  1    5   12  -386.0   0.0  28.0      2   2
   8     ' Ax 4-Truck Frame Y '  1    5   13  -494.0   0.0  28.0      2   2
   9     ' Carbody-L.Bol L Z-s'  1    1   2    -54.0  10.0  43.0      3   3
  10     ' Carbody-L.Bol R Z-s'  1    1   2    -54.0 -10.0  43.0      3   3
  11     ' Carbody-L.Bol F Z-s'  1    1   2    -44.0   0.0  43.0      3   3
  12     ' Carbody-L.Bol B Z-s'  1    1   2    -64.0   0.0  43.0      3   3
  13     ' Carbody-L.Bolst Yaw'  2.1  1   2    -54.0   0.0  43.0      6   4
  14     'L.Bol-Truck Lt Z-sup'  3    2   4    -54.0  38.0  28.0      3   14
  15     'L.Bol-Truck Rt Z-sup'  3    2   4    -54.0 -38.0  28.0      3   14
  16     'L.Bol-Truk Yaw suspn'  1    2   4    -54.0   0.0  28.0      6   9
  17     'L.Bol-Truk Pitch spn'  1    2   4    -54.0   0.0  28.0      5   8
  18     ' Carbody-T.Bol R Z-s'  1    1   3   -440.0 -10.0  43.0      3   3
  19     ' Carbody-T.Bol L Z-s'  1    1   3   -440.0  10.0  43.0      3   3
  20     ' Carbody-T.Bol F Z-s'  1    1   3   -430.0   0.0  43.0      3   3
  21     ' Carbody-T.Bol B Z-s'  1    1   3   -450.0   0.0  43.0      3   3
  22     ' Carbody-T.Bolst Yaw'  2.1  1   3   -440.0   0.0  43.0      6   4
  23     'T.Bol-Truck Lt Z-sup'  3    3   5   -440.0  38.0  28.0      3   14
  24     'T.Bol-Truck Rt Z-sup'  3    3   5   -440.0 -38.0  28.0      3   14
  25     'T.Bol-Truk Yaw suspn'  1    3   5   -440.0  0.0   28.0      6   9
  26     'T.Bol-Truk Pitch spn'  1    3   5   -440.0   0.0  28.0      5   8
  27     'Ax 1-Lead Truck Lt Z'  1    4   10     0.0  39.5  35.0      3   5
  28     'Ax 1-Lead Truck Rt Z'  1    4   10     0.0 -39.5  35.0      3   5
  29     'Ax 1-Truk Yaw suspen'  1    4   10     0.0   0.0  28.0      6   6
  30     'Ax 2-Lead Truck Lt Z'  1    4   11  -108.0  39.5  35.0      3   5
  31     'Ax 2-Lead Truck Rt Z'  1    4   11  -108.0 -39.5  35.0      3   5
  32     'Ax 2-Truk Yaw suspen'  1    4   11  -108.0   0.0  28.0      6   6
  33     'Ax 3-Tral Truck Lt Z'  1    5   12  -386.0  39.5  35.0      3   5
  34     'Ax 3-Tral Truck Rt Z'  1    5   12  -386.0 -39.5  35.0      3   5
  35     'Ax 3-Truk Yaw suspen'  1    5   12  -386.0   0.0  28.0      6   6
  36     'Ax 4-Tral Truck Lt Z'  1    5   13  -494.0  39.5  35.0      3   5
  37     'Ax 4-Tral Truck Rt Z'  1    5   13  -494.0 -39.5  35.0      3   5
  38     'Ax 4-Truk Yaw suspen'  1    5   13  -494.0   0.0  28.0      6   6
  39    'Ax 1 Lt Whl/Rail Lat'   4   10          0.0    29.75    0.0  1
  40    'Ax 1 Rt Whl/Rail Lat'   4   10          0.0   -29.75    0.0  1
  41    'Ax 2 Lt Whl/Rail Lat'   4   11       -108.0    29.75    0.0  2
  42    'Ax 2 Rt Whl/Rail Lat'   4   11       -108.0   -29.75    0.0  2
  43    'Ax 3 Lt Whl/Rail Lat'   4   12       -386.0    29.75    0.0  3
  44    'Ax 3 Rt Whl/Rail Lat'   4   12       -386.0   -29.75    0.0  3
  45    'Ax 4 Lt Whl/Rail Lat'   4   13       -494.0    29.75    0.0  4
  46    'Ax 4 Rt Whl/Rail Lat'   4   13       -494.0   -29.75    0.0  4
  47     ' Ax 1 / Tn Mtr Vert '  1    6   10     0.0   0.0  20.0      3   13
  48     ' Ax 2 / Tn Mtr Vert '  1    7   11  -108.0   0.0  20.0      3   13
  49     ' Ax 3 / Tn Mtr Vert '  1    8   12  -386.0   0.0  20.0      3   13
  50     ' Ax 4 / Tn Mtr Vert '  1    9   13  -494.0   0.0  20.0      3   13
  51     ' Tn Mtr 1 / Trk Vert'  1    6   4    -29.0   0.0  20.0      3   10
  52     ' Tn Mtr 2 / Trk Vert'  1    7   4    -79.0   0.0  20.0      3   10
  53     ' Tn Mtr 3 / Trk Vert'  1    8   5   -415.0   0.0  20.0      3   10
  54     ' Tn Mtr 4 / Trk Vert'  1    9   5   -465.0   0.0  20.0      3   10
  55     ' Lft Side Bearing 1 '  1    1   2    -54.0  26.5  43.0      3   12
  56     ' Rgt Side Bearing 1 '  1    1   2    -54.0 -26.5  43.0      3   12
  57     ' Lft Side Bearing 2 '  1    1   3   -440.0  26.5  43.0      3   12
  58     ' Rgt Side Bearing 2 '  1    1   3   -440.0 -26.5  43.0      3   12
  59     'Ax 1 Rt Vert Damper '  2    4   10     0.0 -39.5  35.0      3   15
  60     'Ax 2 Lt Vert Damper '  2    4   11  -108.0  39.5  35.0      3   15
  61     'Ax 3 Rt Vert Damper '  2    5   12  -386.0 -39.5  35.0      3   15
  62     'Ax 4 Lt Vert Damper '  2    5   13  -494.0  39.5  35.0      3   15
  63     'L.Bol-Truk Lat Damp '  2    2   4    -54.0   0.0  12.0      2   16
  64     'T.Bol-Truk Lat Damp '  2    3   5   -440.0   0.0  12.0      2   16
  65     'Body-Trck 1 Yaw Damp'  2    1   4    -54.0   0.0  43.0      6   17
  66     'Body-Trck 2 yaw Damp'  2    1   5   -440.0   0.0  43.0      6   17
```

```
For each type 1 - parallel connection, list its number, followed by
the identification numbers of the piecewise linear characteristics
for the stiffness and damping, respectively, zero if absent, and the
the combined force or moment limit in extn and compn, lb or in-lb
(if no limit exists, set the F-values outside the expected range).
     Pair #     Stiff PWL     Damp PWL       F-extn.      F-compn.
--------------------------------------------------------------------
For each type 2 - series connection, list its number, followed by
the identification numbers of the piecewise linear characteristics
for the stiffness and damping, respectively, and the stroke limit
in extension and compression for the pair, inches or rad, and the
stiffness of the stop at the limit in lb/in or in-lb/rad (if no
limit exists, set the S-values outside the expected range).
     Pair #     Stiff PWL   Damp PWL    S-extn.     S-compn.   Stop K
--------------------------------------------------------------------
For each type 2.1 - series friction connection, list its number, followed by
the identification numbers of the piecewise linear characteristics
for the friction, and the stroke limit
in extension and compression for the pair, inches or rad, and the
stiffness of the stop at the limit in lb/in or in-lb/rad (if no
limit exists, set the S-values outside the expected range), and the linear
stiffness and linear damping in series with the friction.
     Pair #    Damp PWL   S-extn. S-compn. Stop K  Series Stiff. Series Damp.
--------------------------------------------------------------------
For each type 3 - hysteresis loop characteristic, list its number,
followed by identification numbers for the extension and compression
piecewise linear charateristics, extension and compression force limits,
and a linear viscous damping in lb-sec/in or in-lb-sec/rad.
     Loop #      Extn PWL   Comp PWL    F-extn.  F-compn.   LVB Damping
--------------------------------------------------------------------
\CHARACTERISTIC DATA
        1        1            2            1.0E08       -1.0E08
        2        3            4            1.0E08       -1.0E08
        3        5            6            0.0E08       -1.0E08
        4        7        1.0     -1.0     1.0e9    1.0e9     1.0e6
        5        8            9            0.0E08       -1.0E08
        6       10           11            1.0E08       -1.0E08
        7       12           13            1.0E08       -1.0E08
        8       23           24            1.0E08       -1.0E08
        9       16           17            1.0E08       -1.0E08
       10       18           19            1.0E08       -1.0E08
       11       20           21            1.0E08       -1.0E08
       12       22           0             1.0E08       -1.0E08
       13       25           26            1.0E08       -1.0E08
       14       14           15            1.0E08   -1.0E08       4.5E6
       15       27           28            0.1          -5.6       1.0e6
       16       29           30            2.1          -2.1       1.0e6
       17       31           32            0.08         -0.08      1.0e9
For each type 4 - axle to track characteristic, list an identification
number, IBDAX, its general body number, WRAD, the nominal wheel radius,
INDWH, a wheel rotation index, .F. for solid, .T. for independent wheels,
ITRQ, traction torque input nos. for left and right wheels, 0 for none,
and, for independent wheels, KWHL, DWHL, the axle torsional stiffness
and damping.
   Axle #      WRAD     INDWH      ITRQ-L     ITRQ-R     KWHL     DWHL
--------------------------------------------------------------------
\WHEEL/RAIL ELEMENT
     4.E5     4.E3       12  13
     1          20.0     .F.         0          0        0.0      0.0
     2          20.0     .F.         0          0        0.0      0.0
     3          20.0     .F.         0          0        0.0      0.0
     4          20.0     .F.         0          0        0.0      0.0
List the data required for each piecewise linear function, the PWL
number, the number of break points in each PWL, and ordinate, lb or
in-lb, over abscissa, inches or rad, at each break point.
Note - extension is assumed to be positive for both ordinate and abscissa
       and 0.0 for the first break point indicates symmetry about the origin
```

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 PWL    IBP    Ordinates over Abscissae
-----------------------------------------------------------------------
\PWL DATA
  1      2    -1.00E06     1.00E06                    (locom-bolster lat stiff. )
              -1.0         1.0
  2      2    -1.00E03     1.00E03                    (locom-bolster lat damping)
              -1.0         1.0
  3      4     0.0   600.0   6.85E03    1.0685E05     (primary  -lateral stiff. )
               0.0    0.05   0.1        0.2
  4      3     0.0         1.2E03    1.2E03           (primary  -lateral damping)
               0.0         0.06      1.0
  5      2    -1.00E06     1.00E06               (locom-bolster C.P. vert stiff.)
              -1.0         1.0
  6      2    -1.00E03     1.00E03               (locom-bolster C.P. vert damp. )
              -1.0         1.0
  7      3     0.0         5.77E03    5.77E03        (center plate yaw friction)
               0.0         0.1        1.0
  8      4    -1.5175E05 -5.175E04    0.0      0.0  (stiff primary-vertical stiff.)
              -5.6       -5.5         0.0      1.0
  9      3     0.00        0.655E03    0.655E03      (stiff primary-vert.frictin damp)
               0.0         0.033       1.0
 10      5     0.0  4.15e4  2.78e5   9.1e6   7.98e7  (primary  -yaw stiffness  )
               0.0  0.0023  0.0031   0.0039  0.0293
 11      2    -1.60E05     1.60E05                    (primary  -yaw damping    )
              -1.0         1.0
 12      2     0.0         1.00E05                    (track    -vertical stiff. )
               0.0         1.0
 13      2     0.0         1.00E03                    (track    -vertical damp.  )
               0.0         1.0
 14   7   -2.02E05 -1.02E05 -8.67E04 -4.32E04 -3.27E04 -2.36E04 0.0 (Scdry Vert)
          -4.55    -4.45    -4.3     -2.5     -2.3     -1.7     0.0
 15   6   -2.24E05 -1.24E05 -7.32E04 -5.22E04 -4.17E04 -2.4E04      (Scdry Vrt)
          -4.55    -4.45    -3.0     -2.1     -1.7      0.0
 16      2    -1.0E09      1.0E9                      (Bolster to Truck Yaw Stiff)
              -1.0         1.0
 17      2    -1.0E06      1.0E06                     (Bolster to truck Yaw Damp)
              -1.0         1.0
 18      2     0.0         1.754E04                   (Tn motor to truck stiffness )
               0.0         1.0
 19      2    -1.0E02      1.0E02                     (Tn motor to Truck damping   )
              -1.0         1.0
 20      3     0.0         1.4E04      2.14E05        (sec. lat-bolst truck stiffness)
               0.0         2.0         2.1
 21      3     0.0         9.08E03     9.08E03        (sec. lat-bolst truck damping  )
               0.0         0.1135      1.0
 22      4    -1.0E06      0.0         0.0      1.0E06       (side bearings)
              -1.25       -0.25        0.0      0.25
 23      2     0.0         1.0e8                      (Bolster/Truck Pitch Stiff)
               0.0         1.0
 24      2     0.0         1.0e5                      (Bolster/Truck Pitch Damp)
               0.0         1.0
 25      2    -1.00E06     1.00E06                    (Axle/Tn. Motor Vert stiff. )
              -1.0         1.0
 26      2    -1.00E03     1.00E03                    (Axle/Tn. Motor vert damping)
              -1.0         1.0
 27      2     0.0         3702.0                     (Vert Damper Bushing stiff. )
               0.0         1.0
 28      2     0.0         530.0                      (Vert Damper Damping)
               0.0         1.0
 29      2     0.0         7940.0                     (Lat Damper Bushing stiff. )
               0.0         1.0
 30      2     0.0         400.0                      (Lat Damper Damping)
               0.0         1.0
 31      2    -4.7e7       4.7e7                      (Yaw Damper Bushing stiff. )
              -1.0         1.0
 32      3     0.0         1.98e5     2.01e5          (Yaw Damper Damping)
               0.0         0.0119     0.0253
```