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Federal Railroad Administration

EXTENDED NUCARS SAFETY ASSESSMENT

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

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12 - Safety

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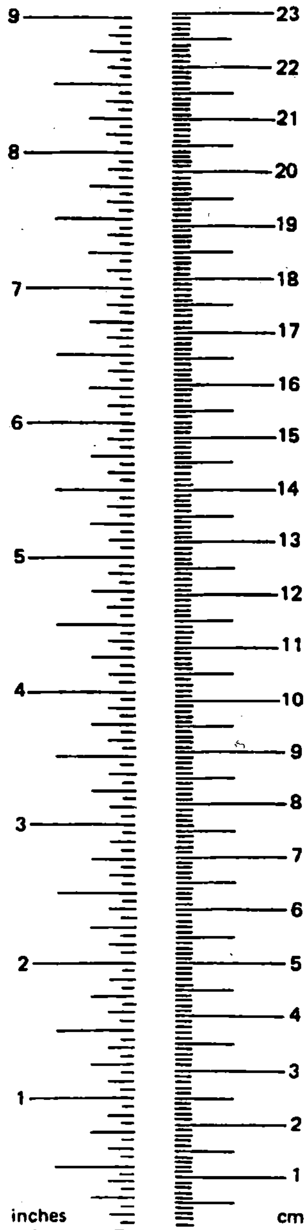
METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

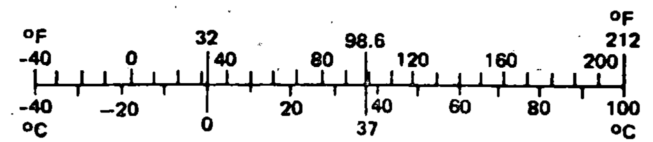
Symbol	When You Know	Multiply by	To Find	Symbol
	LENGTH			
in	inches	*2.50	centimeters	cm
ft	feet	30.00	centimeters	cm
yd	yards	0.90	meters	m
mi	miles	1.60	kilometers	km
	AREA			
in^2	square inches	6.50	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.80	square meters	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 (FRA) and Association of American Railroads (AAR) sponsored research to evaluate the ability of the NUCARS vehicle dynamics simulation program to extrapolate results from Chapter XI tests to permit definition of the safe operating limits of car performance up to the point of derailment and to simulate test regimes in addition to the requirements of Chapter XI. The program involved subjecting a lightweight aluminum coal gondola to on-track tests, and simulation of tests using a computer model for new regimes beyond those required by Chapter XI.

Five new test regimes are evaluated using on-track tests and computer simulations. These include combined lateral and cross level perturbations, a single lateral perturbation, limiting spiral, No. 10 turnout and a crossover. The test results and model predictions show that Chapter XI safety criteria were exceeded in several of the test regimes. Predictions extend the test results up to the point of derailment for several of the test regimes.

The same computer model and test vehicle were used as in the joint FRA-AAR "Safety Aspects of New Trucks and Lightweight Cars, Car 2" research program. Following the recommendations of that test program, small improvements were made to the computer simulations. Good correlation between test and model predictions is shown only for the loaded car.

The instrumented wheel sets used during the track tests were found to be too inaccurate for testing the empty car. Similar problems were encountered in the Car 2 project. The Car 2 project recommended improving the simulation of the friction damping of the car's suspension. This is reiterated here.

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EXECUTIVE SUMMARY

A joint Federal Railroad Administration (FRA) and Association of American Railroads (AAR) research program has extended the range of tests and analyses performed under the Safety Aspects of New Trucks and Lightweight Cars, Car 2 project. Car 2 project evaluated the safety performance of a light weight aluminum coal gondola using the testing and analysis techniques required by the AAR *Manual of Standards and Recommended Practices,* Section C-II, M-1001, Chapter XI, Specifications for Design Fabrication and Construction of Freight Cars. The same techniques were used in this program to evaluate the safety performance of the same test vehicle for an extended range of conditions not previously tested or required by Chapter XI.

The primary objective was to demonstrate the viability of these test and analysis techniques at determining the safety performance envelope of any railroad vehicle. This was accomplished by subjecting the PSMX-111 light weight aluminum coal gondola to a series of tests and computer analyses, which had been developed as an extension of the Chapter XI requirements. This process has extended the validation of the New and Untried Car Analytic Regime Simulation (NUCARS) computer model to test regimes different from those required by Chapter XI. Test results and computer model predictions, in combination with the previous research program's results, have begun to describe the safety performance envelope of the subject test vehicle.

Five new test zones were evaluated:

- Combined 3/4-inch amplitude lateral and 3/4-inch amplitude cross level perturbations. Ten perturbations were constructed with 39-foot wavelength.
- Single lateral perturbation, 3-inch amplitude 39-feet long.
- Limiting spiral with 5 inches of superelevation leading into a 10-degree curve. Spiral length was 88.57 feet.
- Single No. 10 turnout leading into an 8-degree curve.
- Crossover between two parallel tracks consisting of two No. 15 turnouts back to back.

The first two test zones were chosen to provide more severe excitation to the vehicle than is provided by Chapter XI. The third is a revised spiral test zone that was under consideration for inclusion into Chapter XI. The final two are representative of common special track work that all railroad vehicles might encounter on a daily basis.

In general, good correlation was shown between test and NUCARS model for the loaded vehicle. Correlation is somewhat better than that shown in the Car 2 research program. This is mostly due to small changes in the model's description of the suspension recommended in the Car 2 final report. This has resulted in better prediction of the vehicle's lateral behavior.

The same problems encountered in the Car 2 program for the empty car were also encountered here. Although newer and more accurate instrumented wheel sets were used, the accuracy of the measured wheel/rail forces was poor for light loads. In addition the lateral and vertical behavior of the friction wedge damping in the suspension was still not modeled as accurately as was desired for the empty car. New versions of the NUCARS model provide for a more accurate representation of this important suspension element. These two problems resulted in poor correlation between model and test results for all of the empty car regimes.

The NUCARS model was shown to be quite successful at simulating vehicle behavior in turnouts. This expanded capability will be generally available in version 2.0 of NUCARS. Good correlation with test data was shown for the No. 10 turnout. The simulations of the crossover were not quite as successful due to using design case representations of the wheel/rail contact geometries and not actual measured profiles.

The performance of the car was found to exceed Chapter XI safety criteria limits for the combined lateral and cross level perturbations test section. Although derailment was not predicted until 70 mph, test results and model predictions showed large roll angles, dangerous wheel lifts and high lateral to vertical (L/V) force ratios occurring that would limit the safe performance of the vehicle. These occurred above 25 mph for the empty vehicle and near 18 mph for the loaded vehicle.

Visual observations of the single lateral bump indicated that wheel flange climb was occurring, probably due to large angles of attack (AOA) between the wheels and the rails. This flange climb had not been predicted by the model, indicating a need for improved three dimensional wheel/rail contact geometry descriptions in the model. The flange climbing behavior was not evident in the test data either, casting some doubt on the measured L/V ratios. The truck side L/V ratios were, however, predicted and measured to exceed the Chapter XI limiting criterion of 0.6 for the loaded car.

The single lateral bump test zone also revealed a deficiency in the AOA measurement devices used in the tests. Due to their design, these devices turned out to be incapable of giving accurate readings while flange climb was occurring.

The only other test zone that caused the vehicle to show poor performance was the No. 10 turnout. In this case the only Chapter XI limiting criterion that was exceeded was the truck side L/V ratio. Because track construction in a turnout is usually much better than for regular track, exceeding this rail roll over safety criteria in a turnout may not be important, although it is an indicator of high forces that may cause the turnout to require high maintenance.

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1.0 INTRODUCTION

The Federal Railroad Administration (FRA) has sponsored two research projects to investigate the safety aspects of new freight cars.[1,2] These were known as "Safety Aspects of New and Untried Freight Cars" and "Safety Aspects of New Trucks and Lightweight Cars, Car 2." The safety performance of two new and light weight freight cars was analyzed using predictions made with the Association of American Railroads' (AAR) computer model New and Untried Car Analytic Regime Simulation (NUCARS), and the results of on-track tests. The tests and analyses were based on the requirements of the AAR *Manual of Standards and Recommended Pratices*, Section C-II, M-1001, Chapter XI, Specifications for Design and Fabrication of Freight Cars.

The main purpose of these projects was to evaluate the effectiveness of these tests and analyses at measuring vehicle safety performance. Evaluations were also made of the cost and time effectiveness of the specific test and analysis procedures used. A significant benefit was additional validation of the NUCARS computer model for performing Chapter XI type analyses.

These projects were not intended to measure or analyze vehicle performance up to the point of derailment or any other such performance limit, but only to determine conformance with a given performance standard. The intent of this project has been to verify the analytical capabilities of NUCARS up to the point of failure. This has been accomplished by extending the range of tests and analyses to include tests not required by Chapter XI, which would be more severe tests of vehicle performance than currently performed with Chapter XI.

The AAR jointly funded this project with the FRA, contributing the installation and on-track testing over two of the new test sections. The AAR also supported the modeling of the turnout and crossover as a part of its ongoing turnout performance research program.

To allow a direct extension from the previous testing of light weight cars, the same test vehicle was used in this program as was used in the Car 2 research program.

2.0 OBJECTIVE

The objective of this project was to demonstrate the use of the computer simulation model NUCARS in applications additional to those required by Chapter XI. This was to determine whether NUCARS could be used to evaluate the safety performance limits of any car design beyond the limits of the Chapter XI tests and safety criteria.

3.0 PROJECT METHOD

3.1 PROJECT PHILOSOPHY

The original intent was to extend the scope of the second series of FRA tests by performing Chapter XI type tests on the same test vehicle except with greater amplitudes of perturbations and greater speeds than required by Chapter XI. During the previous test program, the test vehicle was found to exceed the Chapter XI safety criteria limits for several of the normal Chapter XI test conditions. In addition the vehicle showed a tendency to hunt severely at speeds above 60 mph, when loaded and empty. Thus the practical safety performance limits had already been achieved for this vehicle, and no increased amplitudes or speeds were required.

It was therefore decided that a number of alternative test sections would be tested and analyzed to determine the test vehicle's performance envelope over a wider range of conditions. This would also verify the NUCARS model's ability to predict performance over these ranges of conditions.

The project's main tasks were as follows:

- Identify and design new test zones
- Build the required test zones
- Perform on-track tests using the same test vehicle as the previous project
- Use NUCARS to predict vehicle performance over the selected test zones
- Compare and analyze test results and NUCARS predictions to determine the limits of vehicle performance

3.2 IDENTIFICATION OF NEW TEST ZONES

Five different test zones were identified:

1. Ten combined 3/4-inch cross level and 3/4-inch lateral perturbations, with 39-foot wavelength
2. Single lateral perturbation, 3-inch amplitude, 39-foot wavelength
3. Eighty-eight-foot-long spiral leading into a 10-degree curve with 5-inch superelevation
4. Single No. 10 turnout leading into an 8-degree curve

5. Two No. 15 turnouts back to back forming a crossover between two parallel tracks

3.2.1 Combined Cross Level And Lateral Perturbations (Down and Out)

The first test zone was based on recent research conducted by Volpe National Transportation Systems Center (VNTSC) into vehicle response to track with combined cross level and lateral perturbations. This perturbation is intended to simulate the effect of poor quality track where trains traversing low joints have pushed the joints outwards. A series of NUCARS simulations were made of a standard 100-ton coal gondola car traversing a test section with combined cross level and lateral perturbations. Several combinations of perturbation amplitudes were simulated, all with a wavelength of 39 feet.

These simulations predicted that a test section with 3/4-inch cross level and 3/4-inch lateral perturbations was the most severe that a standard hopper could traverse at all speeds up to 70 mph. This was therefore chosen as the combination to be used for these tests.

Perturbations were temporarily installed in the Railroad Test Track (RTT) at the Transportation Test Center (TTC). The constructed perturbations were similar to those found in the Chapter XI twist and roll test section. The perturbations were defined by ten 39-foot segments of rail with the joints lowered by 0.75 inches from the centers. The left and right rails had their joints offset by 19.5 feet to provide the varying cross level. The lateral perturbations were introduced such that both rails were offset 0.375 inches at each low joint. When the left rail had a low joint, both rails were offset to the left; when the right rail was low the offset was to the right.

This test section became known as the "down and out" test zone because wherever the rails were pushed down they were also pushed out to the side.

3.2.2 Single Lateral Perturbation

The second test section was developed and installed by the AAR as part of its contribution to this joint research effort. The AAR had been dissatisfied with the accuracy of NUCARS predictions for test sections where lateral vehicle response dominated. Therefore a test section was developed that would induce large lateral motions so that accurate measurements of vehicle response could be made and compared to the NUCARS predictions. This test section would also serve the purpose of providing another perturbation that was much more severe than any of the current Chapter XI test zones.

A limited number of NUCARS simulations were made of a single lateral 3-inch amplitude perturbation of 39-foot wavelength. These indicated that it could be safely negotiated at a speed of at least 30 mph.

3.2.3 Limiting Spiral

Chapter XI requires testing over a spiral with a minimum superelevation change of 1 inch for every 20 feet of spiral. The maximum curvature of the spiral must be at least 7 degrees with a minimum of 3 inches of superelevation. As installed at the TTC, the spiral has a maximum of 12 degrees of curvature with 5 inches of superelevation. The spiral is 200 feet long but all the superelevation change occurs in the middle 100 feet. This became known as the bunched spiral.

There has been some criticism of this spiral being too severe, and not representative of spirals found in revenue service track. Therefore, it was proposed to develop a spiral that was the most severe that could be constructed within the requirements of the FRA Class 2 track standards. This became known as the limiting spiral. It turns out to have even greater rate of change of curvature and superelevation, although it is constructed somewhat differently than the bunched spiral. The new spiral has the superelevation change along the entire length of the spiral, not just in the middle.

The AAR sponsored the installation of this spiral as a part of its continuing efforts to develop the Chapter XI tests and analyses. The AAR installed the spiral on the Wheel/Rail Mechanisms (WRM) test track at the entrance to a 10 degree curve. As constructed, it has a maximum 5 inches of superelevation. All superelevation and curvature change takes place over a distance of 88.57 feet. This provides a rate of change of superelevation 1 inch for every 17.5 feet, which is slightly more severe than the FRA standard.

3.2.4 Single No. 10 Turnout

Chapter XI does not require testing over turnouts. It was therefore decided that these common pieces of special track work should be investigated to explore the maximum safe operating limits.

The chosen turnout is a No. 10 turnout that is part of the permanent installation at the TTC. Tests were performed over the diverging leg of the turnout which leads directly into an 8-degree curve.

3.2.5 Crossover Between Parallel Tracks

A crossover consists of two turnouts placed back to back allowing trains to cross between two parallel tracks. This requires trains to suddenly negotiate a reverse curve in conjunction with the added perturbations due to the two turnouts. Again it was decided that it would be fruitful to explore the operational limits of these common pieces of special track work.

The chosen crossover is part of the permanent installation at the TTC. It consists of two No. 15 turnouts that form a crossover between two parallel tracks on 21.5 foot centers.

3.3 TRACK TESTS

3.3.1 Test Consist

The test vehicle (Figure 1) was the same one used in the FRA Lightweight Car 2 test program. It is a prototype aluminum body coal gondola capable of carrying 110 tons of coal. Due to its light weight construction, the axle loads, when the car is fully loaded, are similar to a normal 100-ton coal gondola. The car, known as PSMX-111, was provided by Trinity Industries.

For the purposes of the FRA Lightweight Car 2 test and this test program, this car was equipped with premium quality three-piece trucks (Figure 2) provided by American Steel Foundries (ASF). The trucks have a modified three-piece design with a primary suspension consisting of rubber shear pads at the axle bearing adaptors. They are designed to center the axles within the pedestal jaws to attempt to maintain the axles square relative to each other. At the same time the rubber's flexibility is intended to allow the axles to be self steering. The trucks are also equipped with variable rate friction snubbers (dependent on vertical load). The design of the friction snubber castings is also modified in an attempt to provide greater resistance to truck lozenging (truck warping).

Figure 1. PSMX-111 Coal Gondola Car

The Department of Transportation's (DOT) T-205 instrumentation test car was coupled to the PSMX-111. It carried the test crew, all the signal conditioning, and data collection computers and other equipment required for the test.

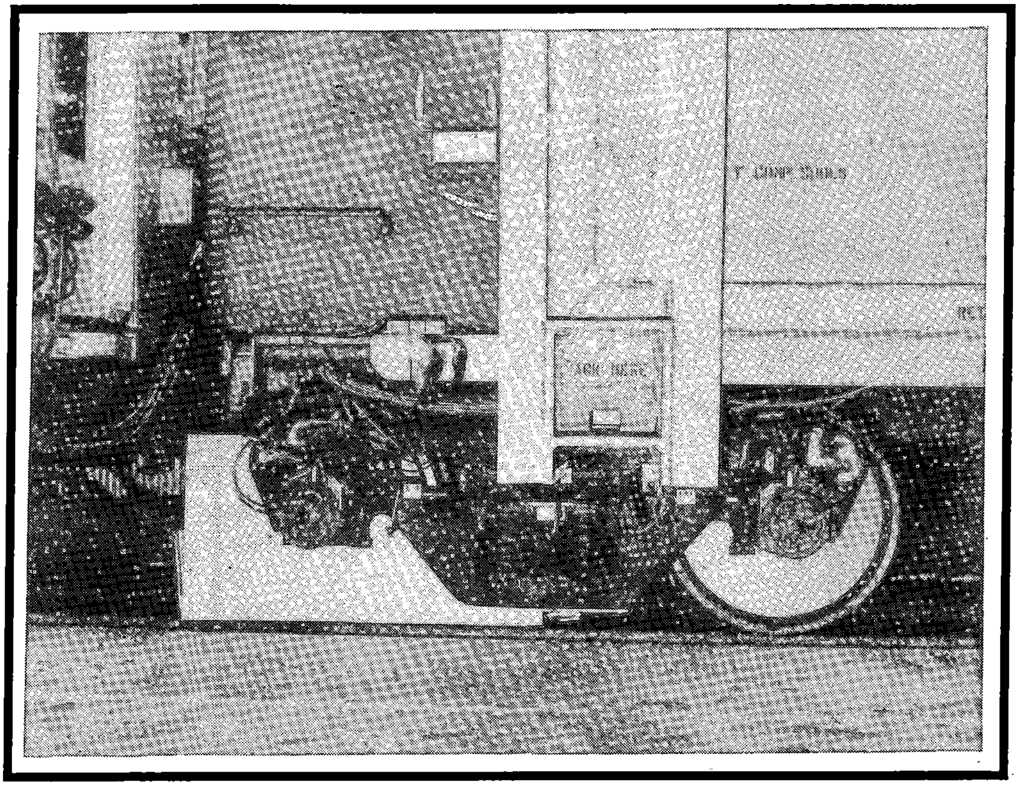

Figure 2. Instrumented Wheel Sets Installed in the PSMX-111 Aluminum Coal Gondola

3.3.2 Instrumentation

Instrumentation installed on PSMX-111 was based around two instrumented wheel sets designed to measure vertical, lateral and longitudinal loads at the wheel/rail interface similar to that used on the Lightweight Car 2 test program. Figure 2 shows the placement of the instrumentation in the lead truck for all tests.

Additional instrumentation included displacement transducers to measure deflections of various suspension elements, accelerometers to measure lateral car body and axle motions, and roll gyro's to measure car body roll angles. Figure 2 also shows some of these transducers in place to measure the vertical spring deflections and the lateral and longitudinal deflections of the primary shear pads at each bearing adaptor. The appendix provides a complete list of the instrumentation used for the tests. Instrumentation used was considerably more extensive than the minimum required by Chapter XI. The extra instrumentation was installed to gain an understanding of the vehicle's dynamic behavior and to permit dynamic measurement of various suspension characteristics.

All data was sampled digitally at 500 Hz and stored for later analysis. Data collection and storage was accomplished using a Hewlett-Packard (HP) 3000 based computer system. Selected data channels were also displayed on strip chart recorders for monitoring test safety.

For this test project, a newer set of instrumented wheel sets was used and was expected to be more accurate and sensitive than the previous ones. Thus it was hoped that the problems previously encountered when measuring wheel/rail forces under empty cars would be reduced.[2]

For the single lateral perturbation tests, three devices for measuring wheel set angle of attack (AOA) relative to the track were installed in the track. The devices were intended to measure, at three different locations in the test zone, the AOA of each wheel set in the test train.

During the tests, very large AOA's were measured. Some were 5 to 10 times greater than believed possible. Track side observers could see the wheels rising and falling as they passed by the AOA frames. The flanges of the test wheels appeared to be attempting to climb the rails in the vicinity of the AOA frames. For the AOA frames to function correctly, the wheels must maintain the same vertical position relative to the measurement device while they pass in front of the measuring light beams. Thus all AOA data gathered is believed to be erroneous and none has been analyzed.

Two video cameras were installed by the AAR under the side frames of the lead truck, which allowed viewing of the contact area between the wheels of the lead axle and the rails. The images were displayed inside the instrumentation car and recorded on video tape. The images were part of a system the AAR is developing for studying the wheel rail contact position under dynamic conditions. The system is intended to capture the video images, digitize the images and analyze them to determine the position of the contact between the wheel and rail.

The plywood shield surrounding the lead axle in Figure 2 was installed to prevent glare and keep light levels uniform for this video system. Unfortunately the AAR has not completed the analyses of these data so no results are included in this report.

3.3.3 Test Data Analysis

Test data that was stored on digital disk was analyzed using the TTC's HP computer based data analysis package. This computer performs digital filtering, calculation of statistics, and arithmetical combinations of data from several measurements to create "synthetic" data channels. The appropriate data was calculated using this software and then transferred to PC-compatible media for comparison with the NUCARS model predictions.

The main data of interest are based upon the requirements for Chapter XI tests. These are:

- **Wheel L/V ratio**, the ratio of lateral to vertical force on a single wheel; Chapter XI limiting value is 1.0
- **Axle sum L/V ratio**, the instantaneous sum of the absolute values of the wheel L/V ratios on one axle; Chapter XI limiting value is 1.4
- **Truck side L/V ratio**, the instantaneous sum of the lateral loads of all wheels on one side of a truck divided by the instantaneous sum of the vertical loads on the same wheels; Chapter XI limiting value is 0.6
- **Minimum percent wheel load**, the actual minimum vertical wheel load divided by the normal static vertical load on that wheel, given as a percentage; Chapter XI limiting value is 10 percent

Other data such as car body roll angle and various suspension deflections were calculated as needed. In most instances statistical data such as maximum and minimum values are all that were calculated. These have been compared to the corresponding values from the NUCARS predictions.

3.4 MATHEMATICAL MODELING

NUCARS model predictions were made post test for all the test zones. The models of the loaded and empty car were essentially the same as the models used for the Lightweight Car 2 project. The input files describing these cars are contained in Appendix B of the final report for the Lightweight Car 2 project.[2] Based on the comparisons of test results and model predictions for the Car 2 project, one suspension characteristic was recommended to be changed to more accurately represent the test vehicle. In accordance with this recommendation, the longitudinal stiffness of the primary rubber shear pads was reduced from 38.1×10^3 lb/in to 27.7×10^3 lb/in.

Due to time and budget constraints in completing the analyses, it was not possible to follow other recommendations of the Car 2 project to modify the models. The most important of these was to change the method for simulating the truck's friction castings. New methods have been under development by the AAR but were not available in time to complete this project. The inability to change the simulation approach for the friction castings probably resulted in errors for the single lateral bump, the turnout, and the crossover simulations, especially for the empty car.

Track geometry of the test zones was surveyed using hand measurements and the data was input into the NUCARS model. Measurements in the test zone were not made as frequently as the ENSCO geometry measurements were made for the Lightweight Car 2 tests, which were made every foot. The hand survey measured the track at each peak and valley in the perturbed track sections. Therefore, the major deviations of the actual track from the intended shapes have been included, but the track roughness has not been accurately included in the NUCARS simulations.

Measurements of the actual wheel on rail profile geometries were also made for each test zone, and were included in the NUCARS model. In the case of the turnout, several rail profiles were measured, since the profiles vary considerably with position in the turnout. All rail profiles were included in the NUCARS model.

No measured rail profiles were available for the crossover. Therefore, design values were used. It is believed, due to the sharp angle of the turnouts that make up the crossover, the lead outside wheels would be in full flange contact most of the time. Therefore, it is expected that using the theoretical rail profile would give similar results to the measured profiles.

The NUCARS simulations of the turnout and the crossover for this project used a non-standard version of NUCARS, specially developed by the AAR as a part of its alternative turnouts research project.[3] This version allows the wheel/rail contact geometry to be varied along the length of the turnout to simulate the different cross sectional geometries at various positions such as the switch points, frog, and guard rails. The model also allows the simulation of contact with the back of the wheel flange such as occurs at the guard rails. These refinements for simulating turnouts have since been included in the latest version of NUCARS.

The AAR sponsored some of the turnout NUCARS modeling effort as a part of its contribution to this project.

4.0 TEST RESULTS AND MODEL PREDICTIONS

4.1 COMBINED CROSS LEVEL AND LATERAL PERTURBATIONS (DOWN AND OUT)

Figures 3 and 4 show comparisons of the test results and model predictions of the minimum percent wheel loads for the empty car traversing the down and out test zone. The measured values are all less than the predicted values, with the car showing wheel lift on the lead axle at 25 mph and above. The poor correlation between the model and test data is due to the model not accurately simulating the surface roughness in the track as described in Section 3.4, and the inaccurate simulation of the combined vertical and lateral action of the friction damping in the truck as described in Section 3.4. The model does however show similar trends with the vertical load dropping sharply at 25 mph to a minimum at 30 mph. Track tests were halted at 30 mph due to the wheel lift. The model predictions do not show derailment until 70 mph.

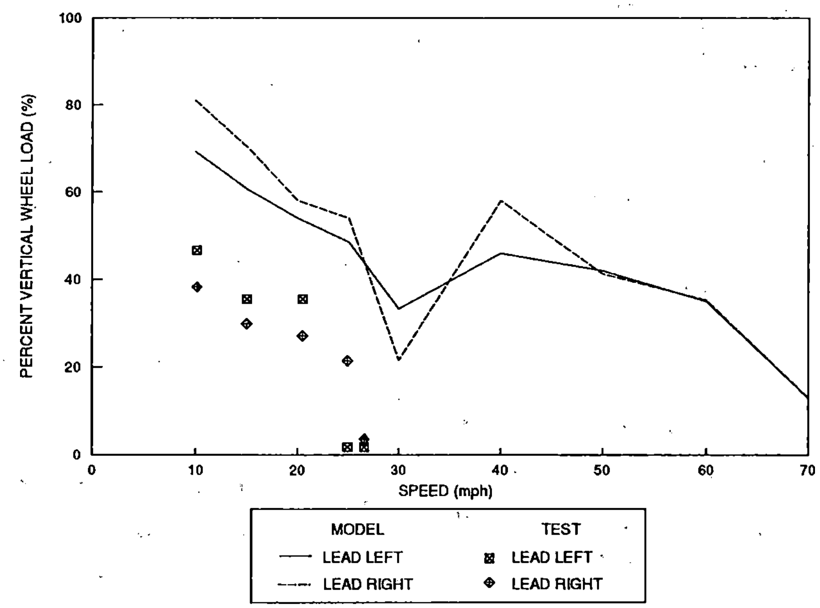

Figure 3. Minimum Percent Wheel Loads for Axle 1 of the Empty Car in the Down and Out Test Zone

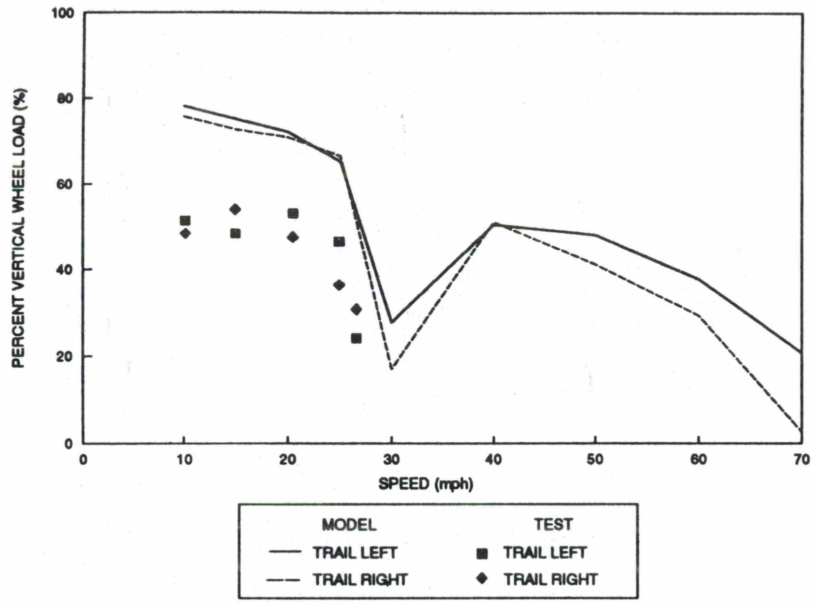

Figure 4. Minimum Percent Wheel Loads for Axle 2 of the Empty Car in the Down and Out Test Zone

The test results for axle 2 show no sign of wheel lift. This may be due to the inaccuracies of the instrumented wheel sets when running at light loads. Although the instrumented wheel sets used for this test are more accurate than the ones used in the Lightweight Car 2 test program, the very light weight of the car (5000 lb static wheel load) when empty could lead to inaccuracies in the measurements of the vertical and lateral loads. The instrumented wheel sets are estimated to have a resolution of around ±500 pounds for the vertical load and between ±500 and ±1000 pounds in the lateral direction. The variation could lead to errors in calculating percent of static vertical wheel load, as well as showing zero wheel load when there may have been as much as 500 pounds on the rails. Large errors could also result in the calculation of the L/V ratios.

Figures 5 and 6 compare the measured and predicted wheel L/V ratios for axle 1 (lead) and axle 2 (trail) for the empty car. Again the trends of the model predictions are similar to the actual test data, with the model showing a large increase in lead axle L/Vs above 25 mph.

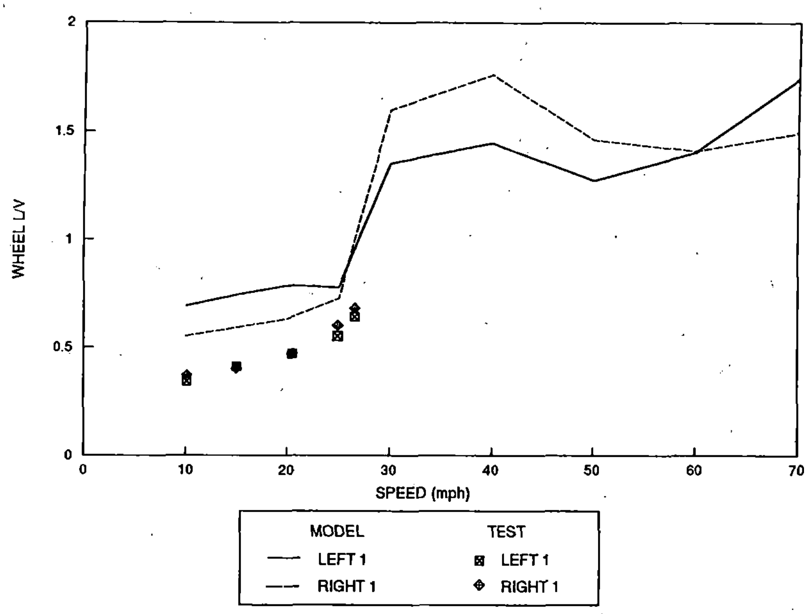

Figure 5. Maximum Wheel L/V Ratios for Axle 1 of the Empty Car in the Down and Out Test Zone

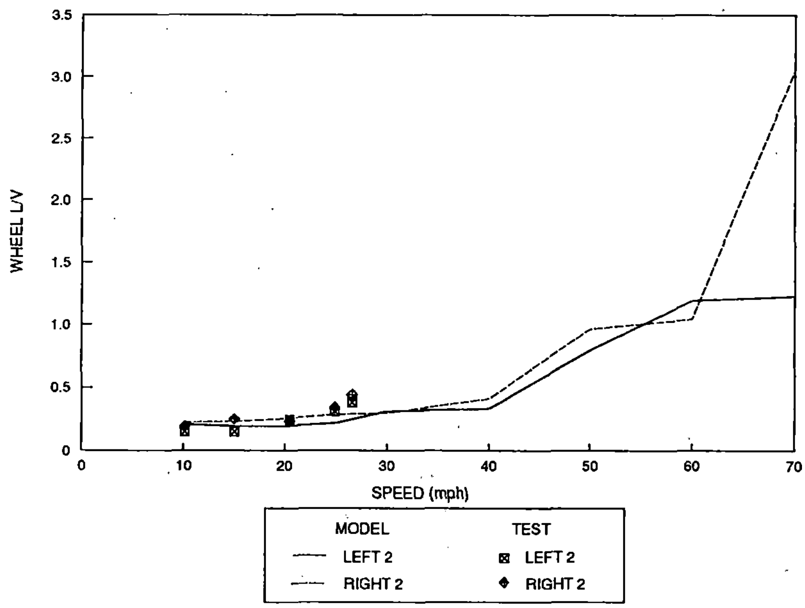

Figure 6. Maximum Wheel L/V Ratios for Axle 2 of the Empty Car in the Down and Out Test Zone

The correlation between test results and model predictions is better for the loaded car. Figures 7 and 8 compare the test results and model predictions of minimum vertical wheel load of the loaded car in the down and out test zone. The match is very good except that the test data shows wheel lift on the lead axle at 20 mph, while the model predictions only reach a minimum of 20 percent of the static load.

The model was run only for speeds of 15, 17.5 , 20 and 25 mph in the region of where minimum wheel loads were predicted. It is likely that if other speeds between 17.5 and 20 mph were simulated lower minimum loads would be predicted, providing a better match with the test data. Unfortunately budget constraints prevented performing these additional simulations.

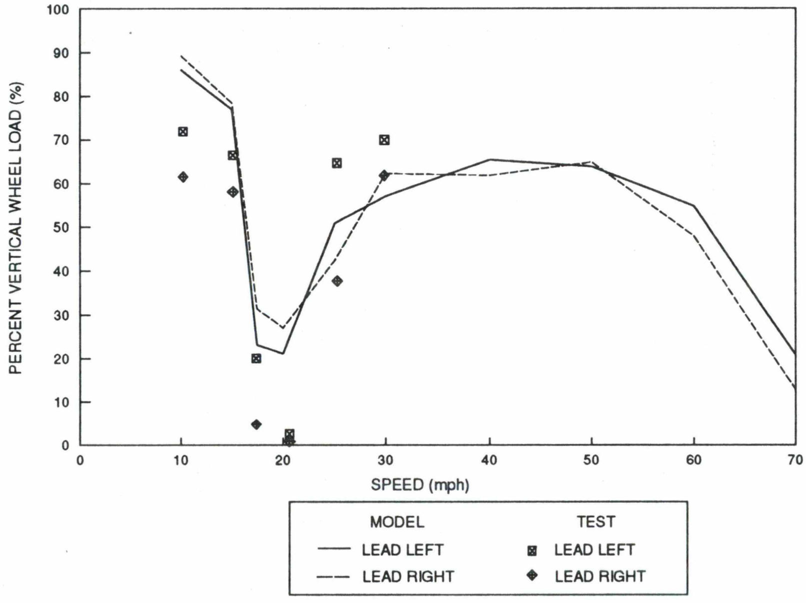

Figure 7. Minimum Percent Wheel Loads for Axle 1 of the Loaded Car in the Down and Out Test Zone

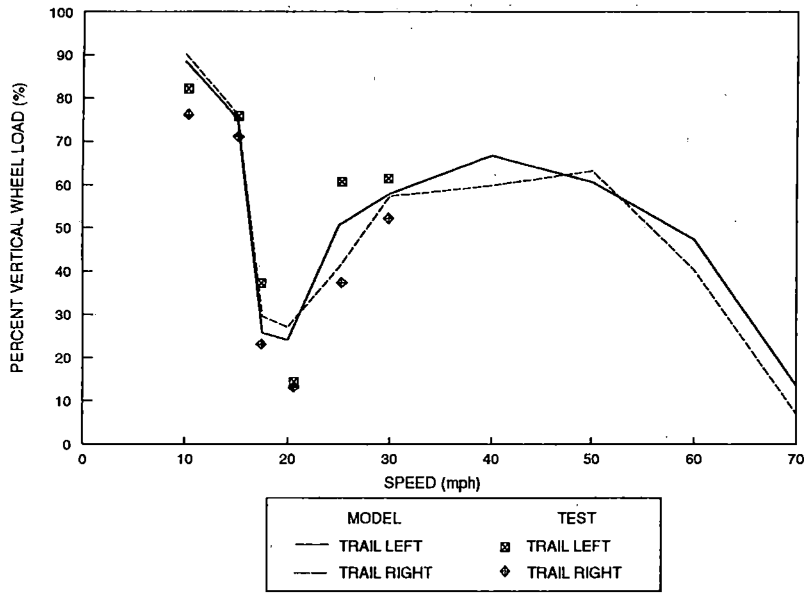

Figure 8. Minimum Percent Wheel Loads for Axle 2 of the Loaded Car in the Down and Out Test Zone

Predicted roll angles exceed the recommended Chapter XI maximum of 6 degrees at 20 mph, but predicted wheel L/V ratios are well within safe limits.

At speeds over 70 mph wheel L/V ratios and roll angles are all predicted to be increasing, while minimum wheel loads are decreasing. Predicted derailment is imminent at speeds over 70 mph.

Good correlation is also shown in the comparison between predicted and measured car body roll angles shown in Figure 9. The plot also indicates a secondary roll resonance above 70 mph.

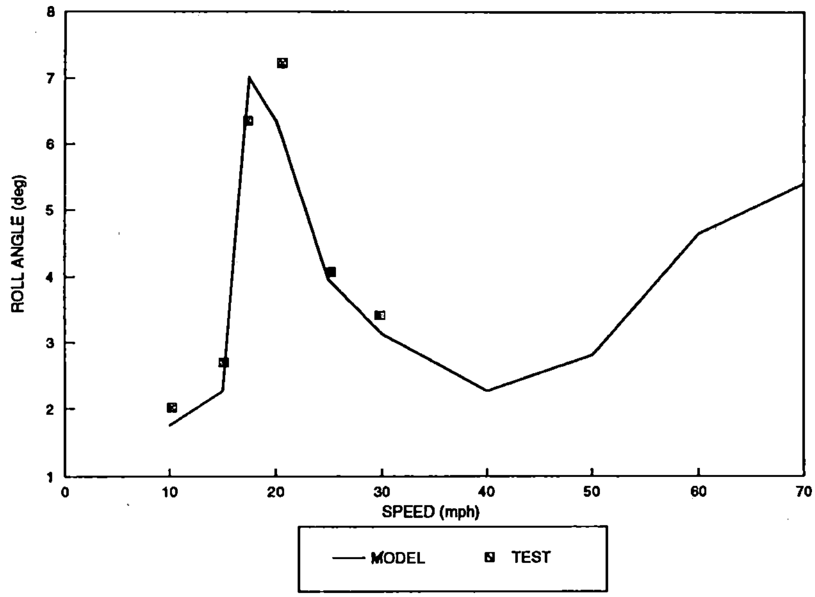

Figure 9. Maximum Car Body Roll Angles for the Loaded Car in the Down and Out Test Zone

Although wheel lift almost occurs, no large lateral forces are present on the unloaded wheel. Therefore, the wheel L/V ratios shown in Figures 10 and 11 are all relatively low, well below the Chapter XI limiting criterion of 1.0. The test data also compares well with the model predictions, with an increase in leading wheel L/V apparent at 20 mph for both model and test results. Again the model predicts deteriorating performance up to 70 mph where derailment is imminent.

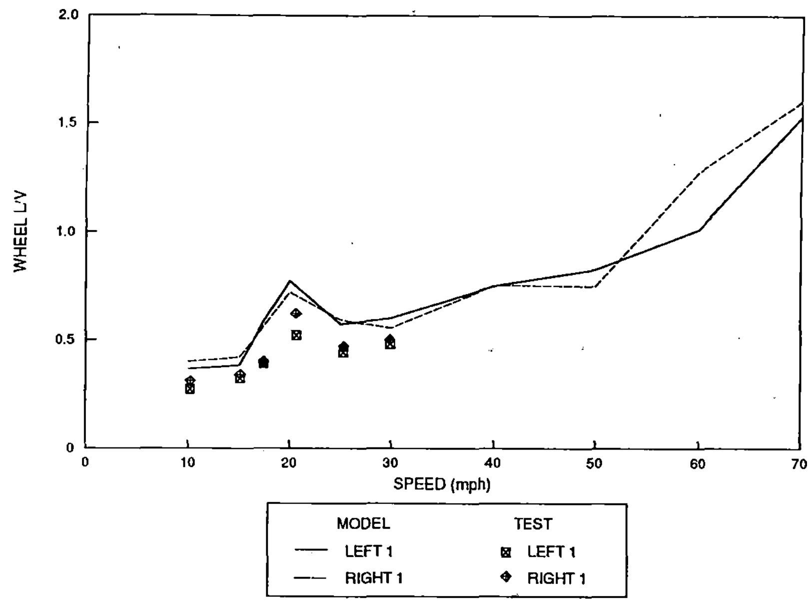

Figure 10. Maximum Wheel L/V Ratios for Axle 1 of the Loaded Car in the Down and Out Test Zone

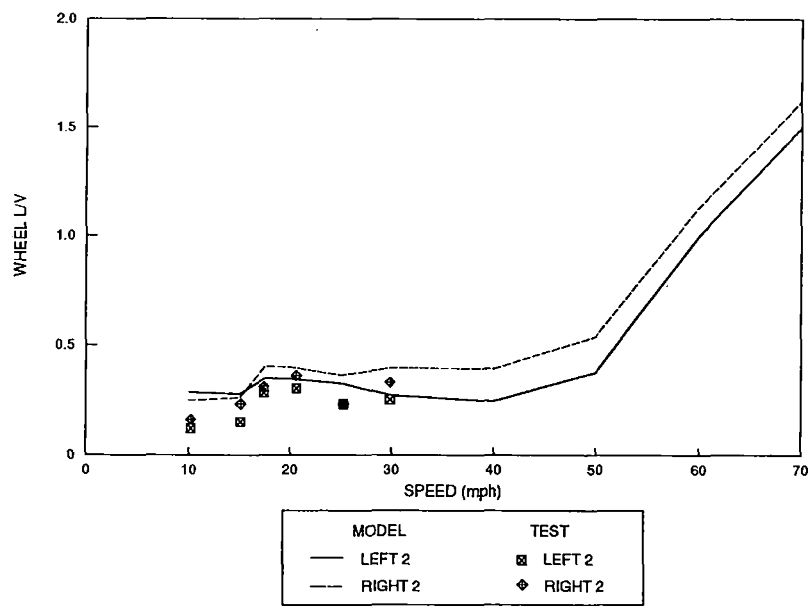

Figure 11. Maximum Wheel L/V Ratios for Axle 2 of the Loaded Car in the Down and Out Test Zone

4.2 LIMITING SPIRAL ENTRY

The correlation is poor between model and test results for the empty car entering the limiting spiral. This is clearly illustrated in Figures 12 through 15, which show the wheel L/V ratios and the minimum percent wheel loads. The measured L/V ratios on the lead axle compare well with the NUCARS simulations, but the rest of the data shows a wide scatter. Although the measured wheel loads do not fall below 20 percent of the static load, they are much lower than the predicted values. This is partly due to the model not including the actual track roughness, but only the general shape of the perturbation.

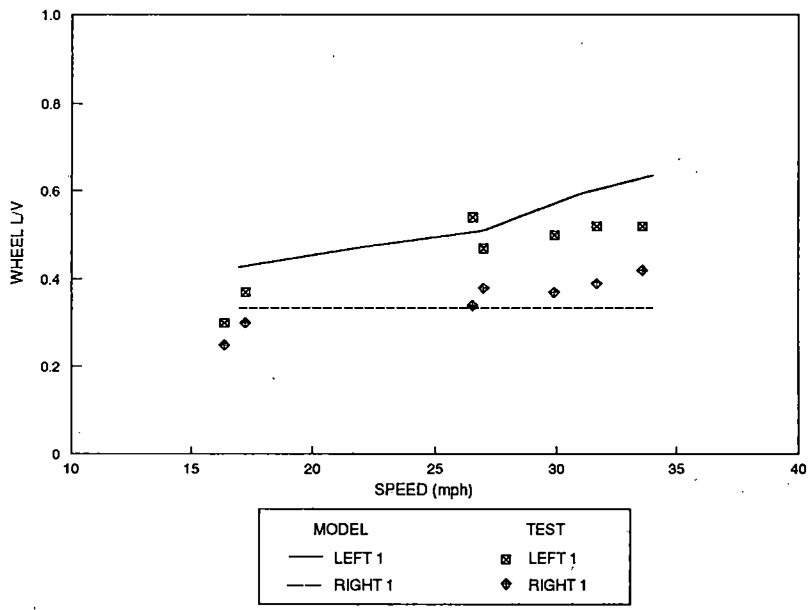

Figure 12. Maximum Wheel L/V Ratios for Axle 1 of the Empty Car in the Limiting Spiral Entry Test Zone

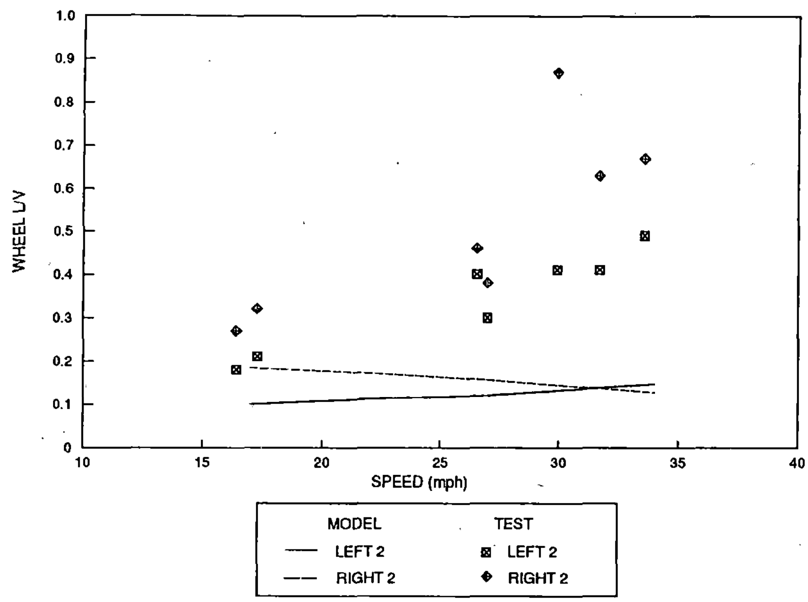

Figure 13. Maximum Wheel L/V Ratios for Axle 2 of the Empty Car in the Limiting Spiral Entry Test Zone

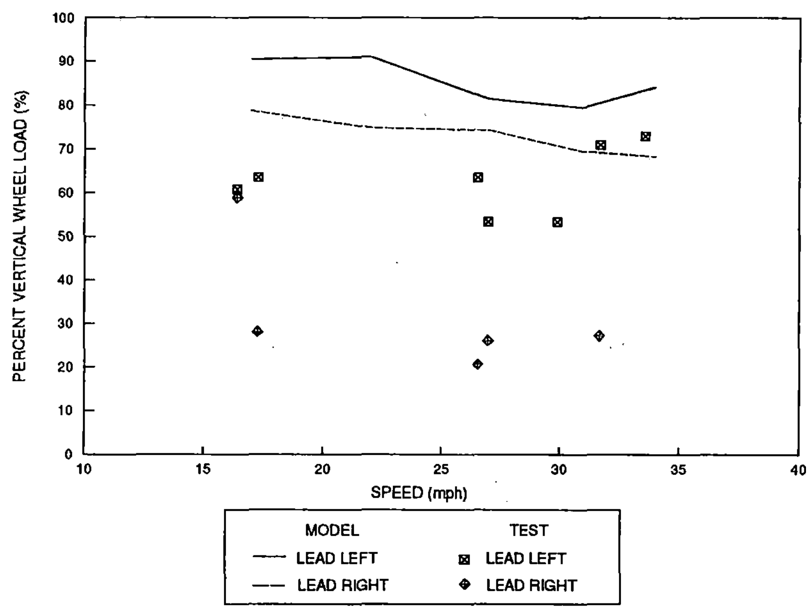

Figure 14. Minimum Percent Wheel Loads for Axle 1 of the Empty Car in the Limiting Spiral Entry Test Zone

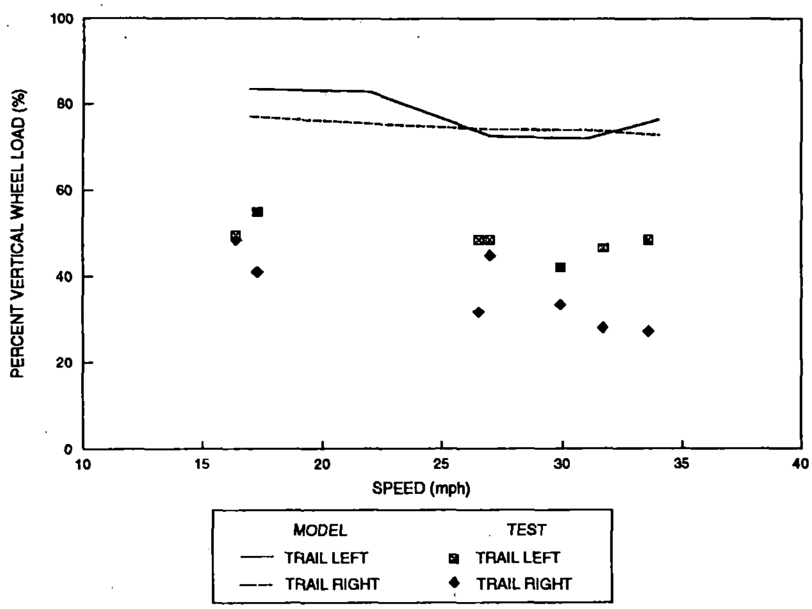

Figure 15. Minimum Percent Wheel Loads for Axle 2 of the Empty Car in the Limiting Spiral Entry Test Zone

Another source of error could be the instrumented wheel sets. As previously mentioned, the possible accuracy errors in the measurement of vertical and lateral loads can lead to large variations in the calculated percent vertical loads and L/V ratios.

The predictions for the loaded car match the test data much more closely, with wheel L/V ratios (shown in Figures 16 and 17) being much lower than the Chapter XI limiting criteria of 1.0. The minimum wheel loads (Figures 18 and 19) are all well above the limiting criteria of 10 percent of the static load. Test results do however show greater variation from the NUCARS predictions, probably due to the absence of track roughness.

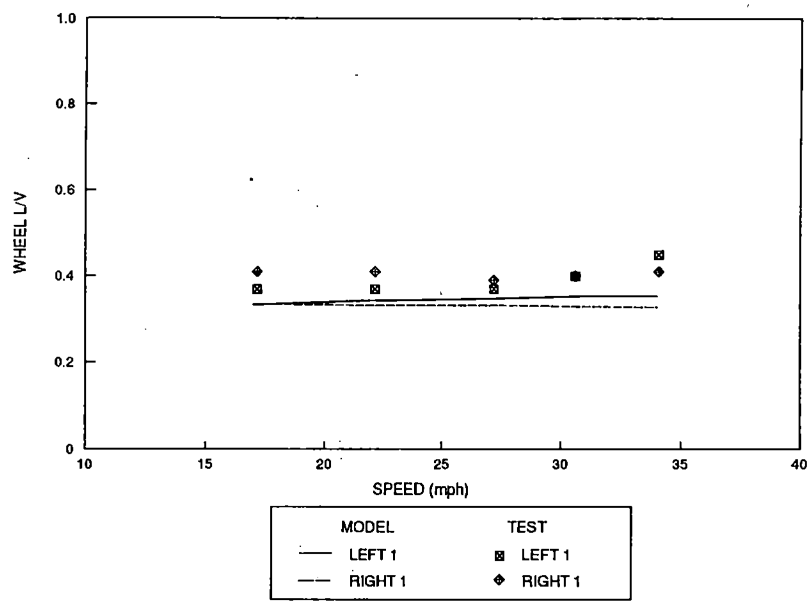

Figure 16. Maximum Wheel L/V Ratios for Axle 1 of the Loaded Car in the Limiting Spiral Entry Test Zone

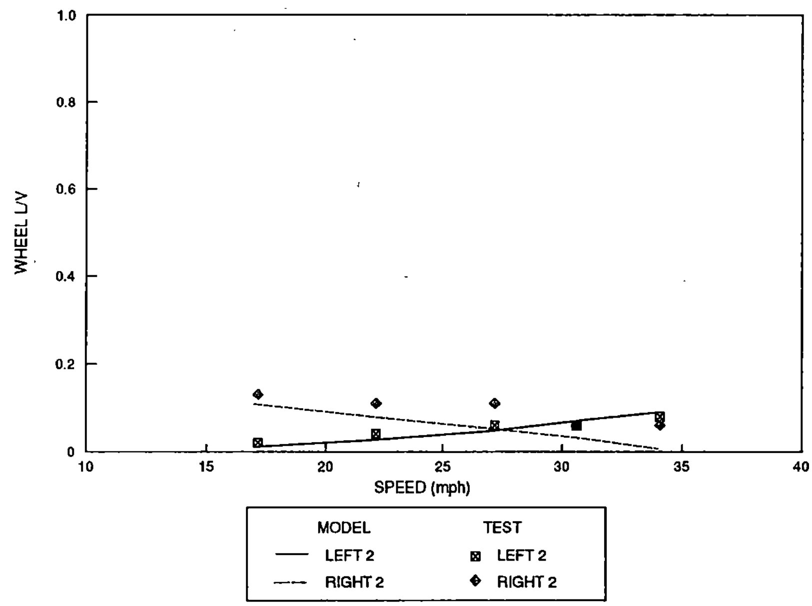

Figure 17. Maximum Wheel L/V Ratios for Axle 2 of the Loaded Car in the Limiting Spiral Entry Test Zone

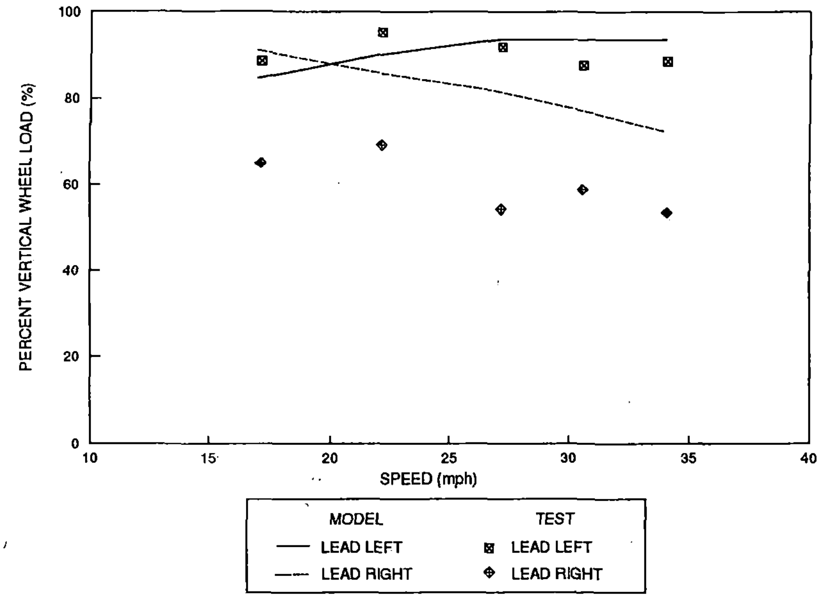

Figure 18. Minimum Percent Wheel Loads for Axle 1 of the Loaded Car in the Limiting Spiral Entry Test Zone

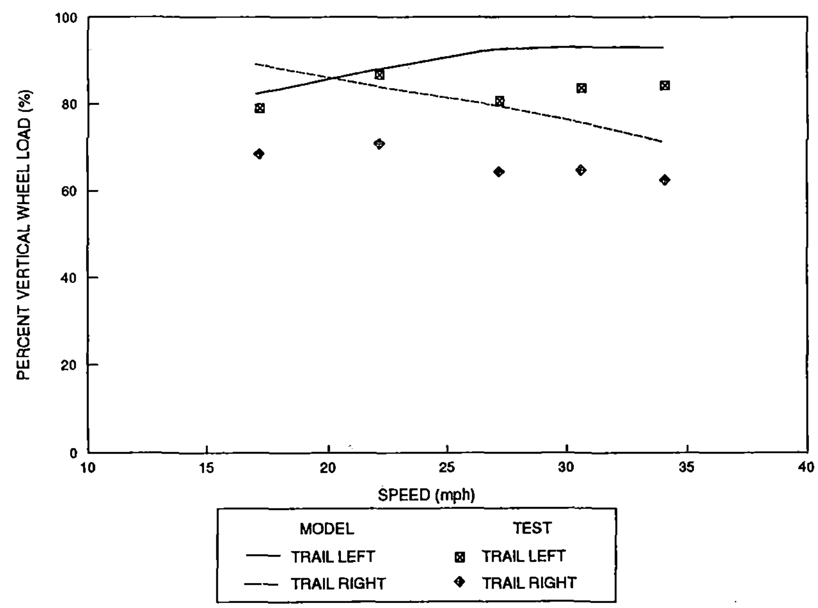

Figure 19. Minimum Percent Wheel Loads for Axle 2 of the Loaded Car in the Limiting Spiral Entry Test Zone

4.3 LIMITING SPIRAL EXIT

Results for the empty car exiting the limiting spiral shown in Figures 20 to 23 are similar to the results entering the limiting spiral. As with previous empty car cases, correlation is poor. Measured L/V ratios shown in Figures 20 and 21 are greater than the predicted values. They are however less than the Chapter XI limiting value of 1.0. The measured minimum percent wheel loads are also less than the predicted values. The differences between test results and model predictions are probably due to the lack of track roughness in the NUCARS model and the possible errors in the instrumented wheel set data mentioned in previous sections.

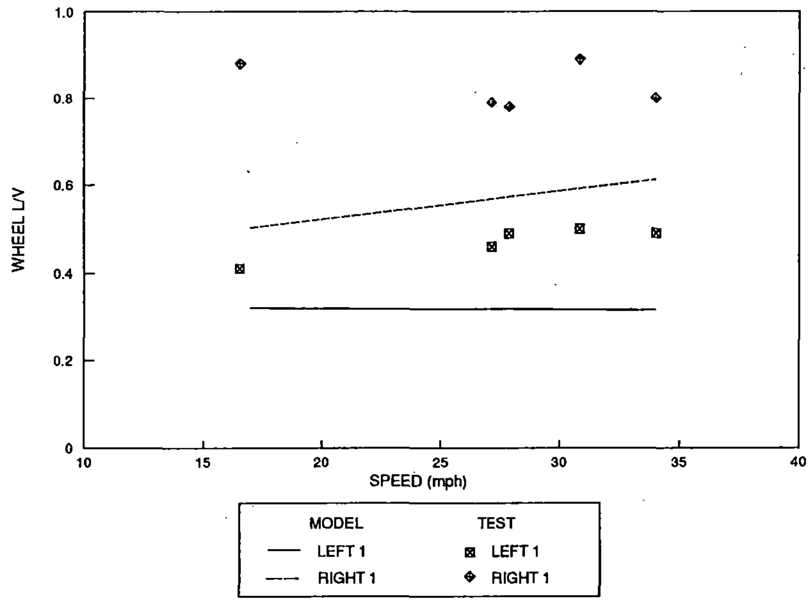

Figure 20. Maximum Wheel L/V Ratios for Axle 1 of the Empty Car in the Limiting Spiral Exit Test Zone

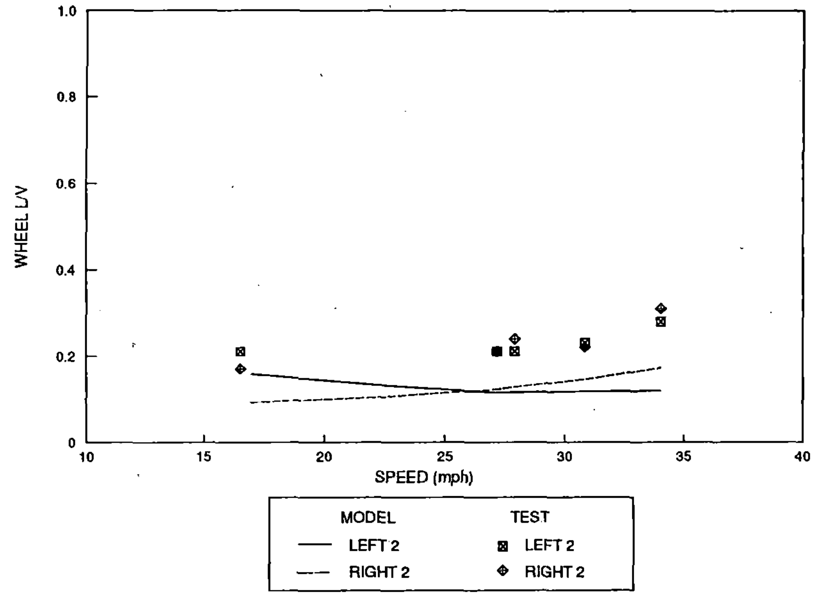

Figure 21. Maximum Wheel L/V Ratios for Axle 2 of the Empty Car in the Limiting Spiral Exit Test Zone

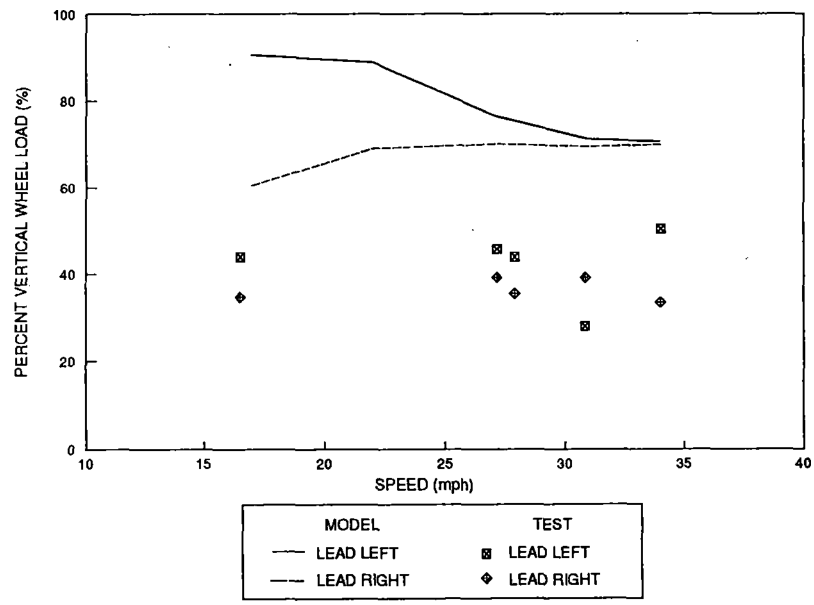

Figure 22. Minimum Percent Wheel Loads for Axle 1 of the Empty Car in the Limiting Spiral Exit Test Zone

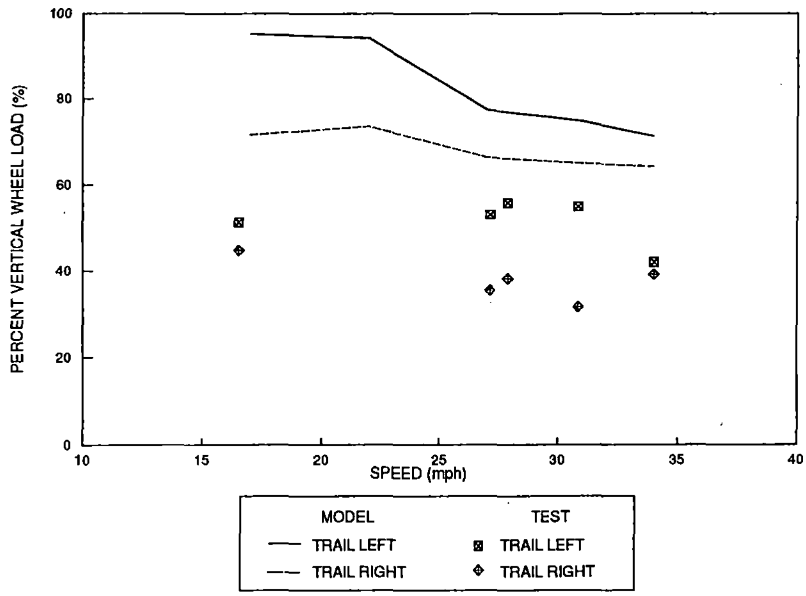

Figure 23. Minimum Percent Wheel Loads for Axle 2 of the Empty Car in the Limiting Spiral Exit Test Zone

Test results for the loaded car, shown in Figures 24 to 27, match the NUCARS predictions much better than for the empty car. The maximum wheel L/V ratios are all less than 0.5, much less than the Chapter XI limiting value of 1.0. The measured minimum percent wheel loads are less than the predicted values, but follow the same trends, remaining well above the Chapter XI limiting value of 10 percent. The difference is again probably due to the lack of track roughness in the NUCARS model.

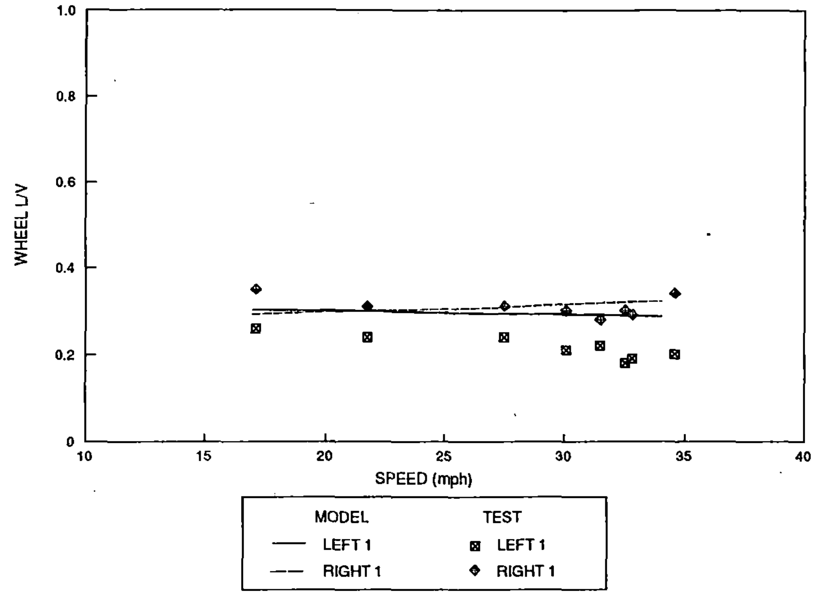

Figure 24. Maximum Wheel L/V Ratios for Axle 1 of the Loaded Car in the Limiting Spiral Exit Test Zone

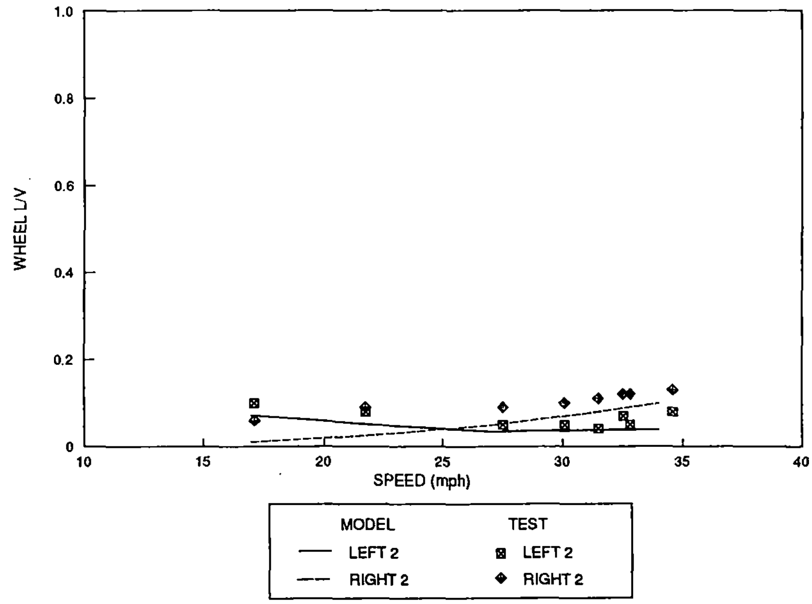

Figure 25. Maximum Wheel L/V Ratios for Axle 2 of the Loaded Car in the Limiting Spiral Exit Test Zone

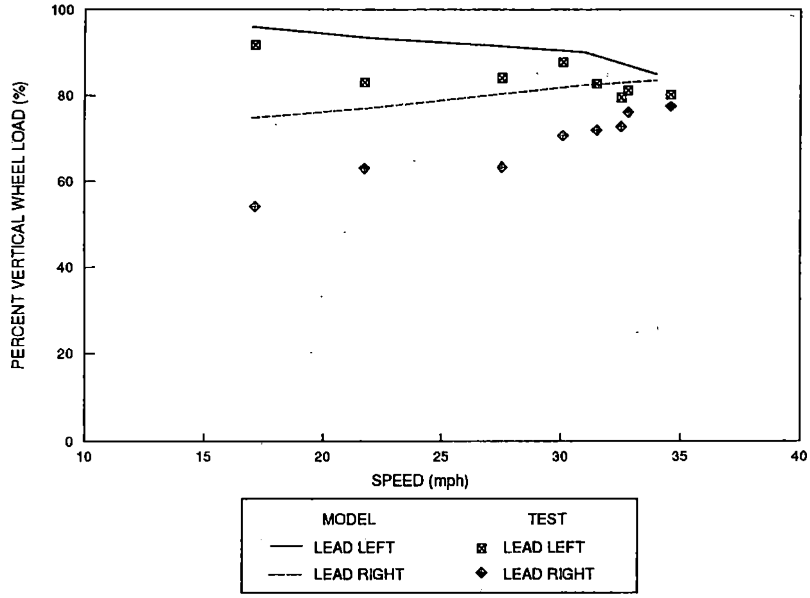

Figure 26. Minimum Percent Wheel Loads for Axle 1 of the Loaded Car in the Limiting Spiral Exit Test Zone

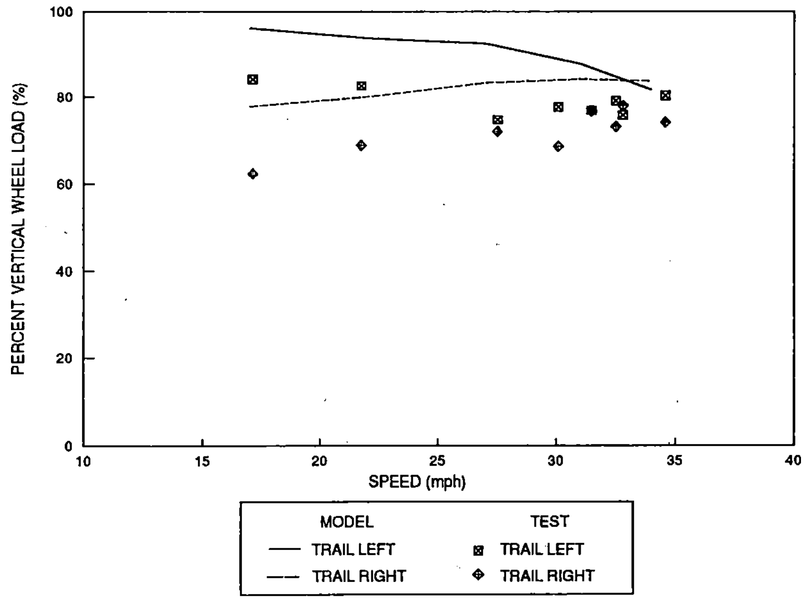

Figure 27. Minimum Percent Wheel Loads for Axle 2 of the Loaded Car in the Limiting Spiral Exit Test Zone

4.4 SINGLE LATERAL BUMP

Figures 28 through 33 show test results and model predictions for the empty car negotiating the single lateral bump. The model in general appears to predict worse behavior than indicated by the test results. Measured maximum wheel L/V ratios are all less than predicted, with predicted values exceeding the Chapter XI limiting criteria of 1.0 at the highest test speed of 25 mph. Predicted L/V ratios rise to 1.2 at 35 mph. A general trend of rising L/V with speed is however shown by the test data.

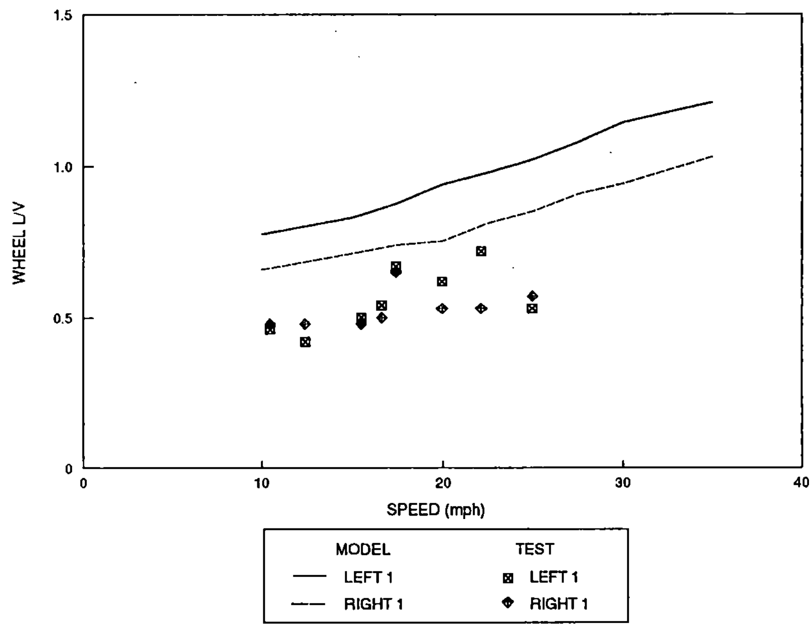

Figure 28. Maximum Wheel L/V Ratios for Axle 1 of the Empty Car in the Single Lateral Bump Test Zone

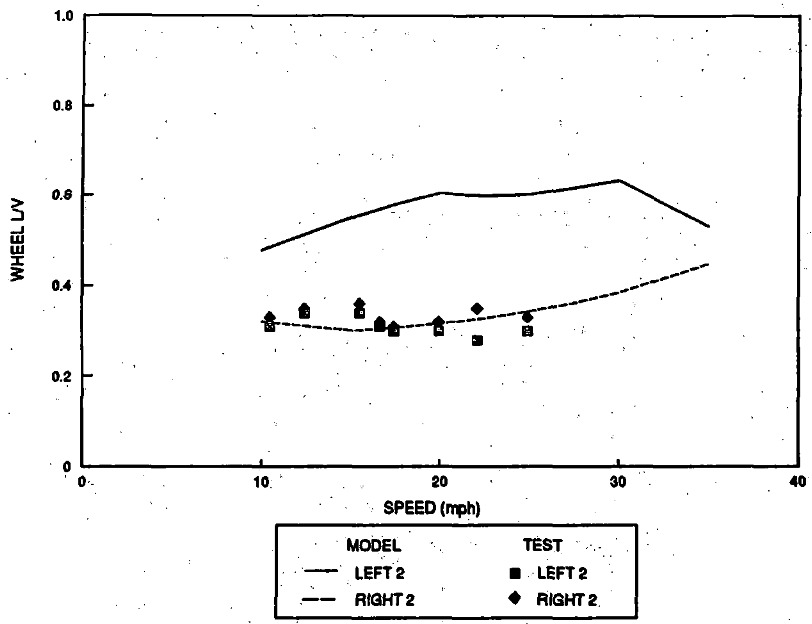

Figure 29. Maximum Wheel L/V Ratios for Axle 2 of the Empty Car in the Single Lateral Bump Test Zone

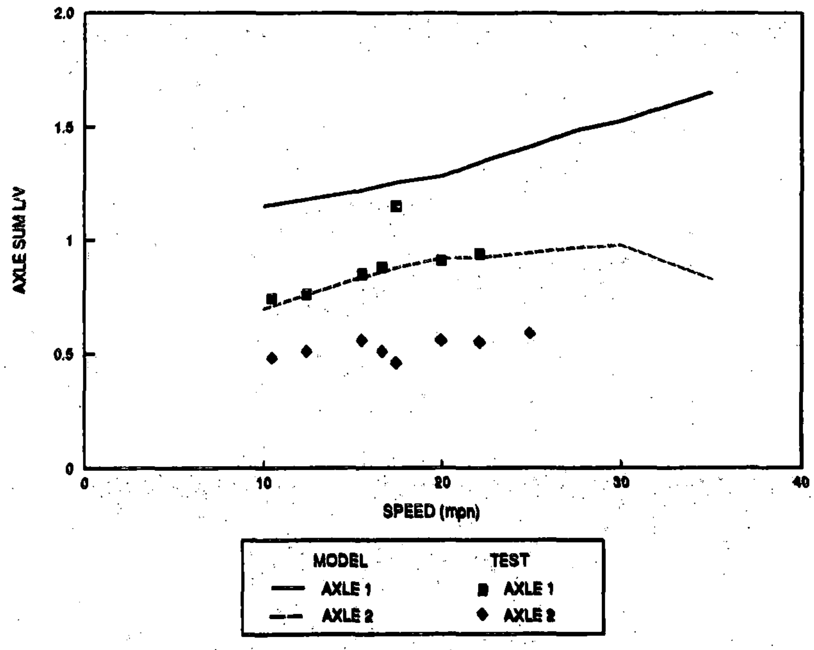

Figure 30. Maximum Axle Sum L/V Ratios for the Empty Car in the Single Lateral Bump Test Zone

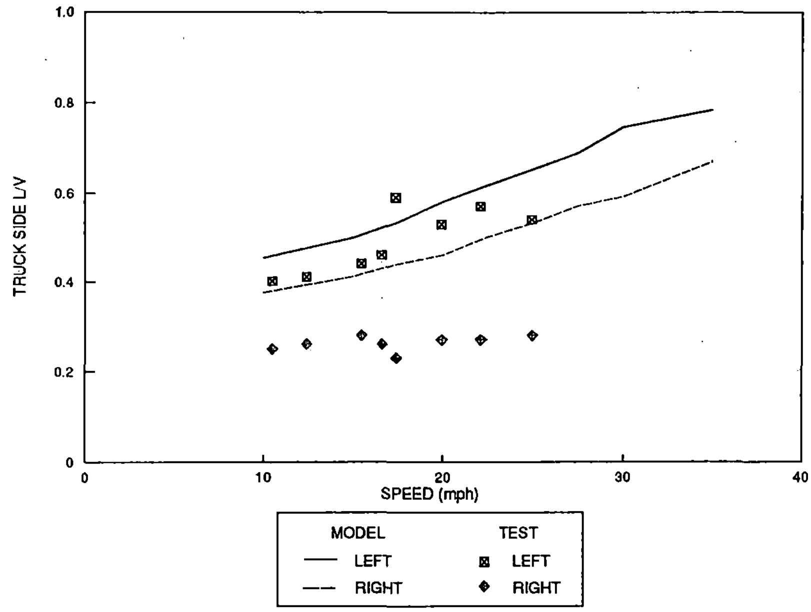

Figure 31. Maximum Truck Side L/V Ratios for the Empty Car in the Single Lateral Bump Test Zone

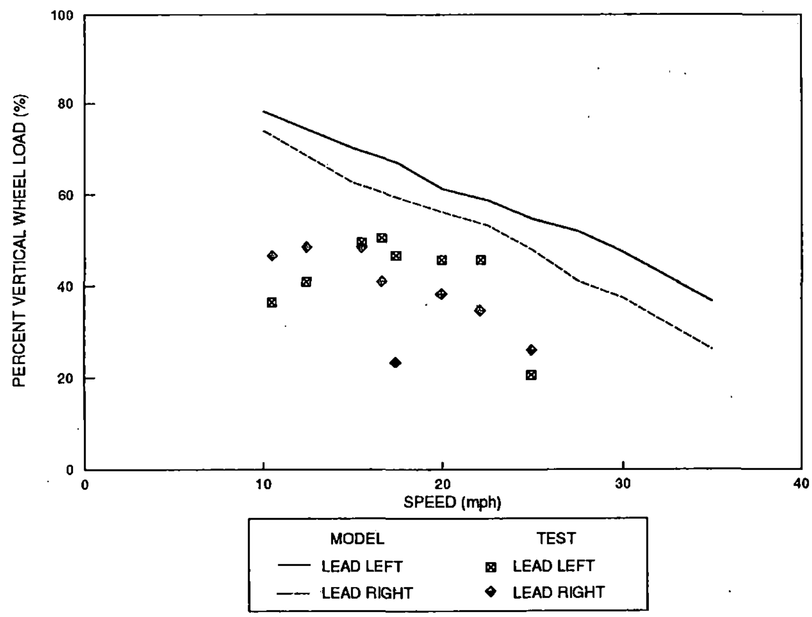

Figure 32. Minimum Percent Wheel Loads for Axle 1 of the Empty Car in the Single Lateral Bump Test Zone

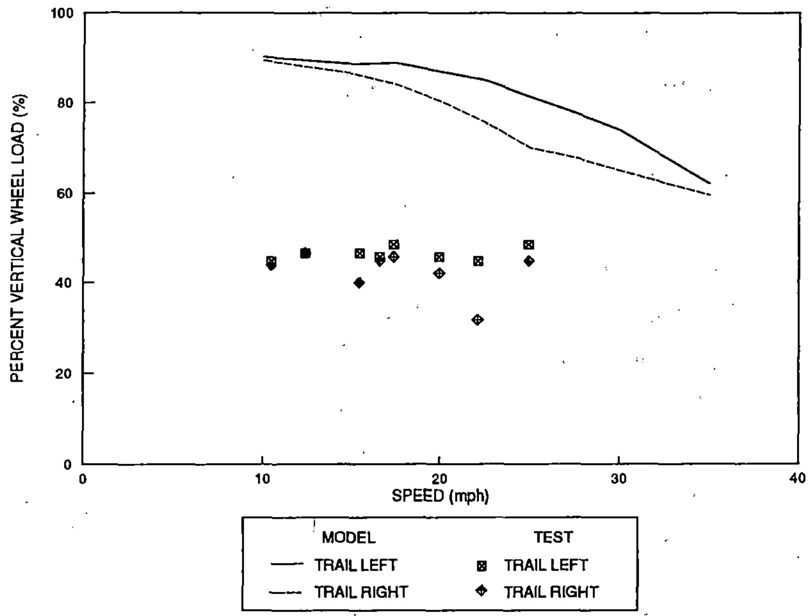

Figure 33. Minimum Percent Wheel Loads for Axle 2 of the Empty Car in the Single Lateral Bump Test Zone

Measured maximum axle sum L/V ratios are also less than the predicted values. Measured maximum truck side L/V ratios however match the model predictions much better, approaching the Chapter XI limiting value of 0.6 at the 25 mph maximum test speed. Trends of the test data agree with the model predictions which rise to almost 0.8 at 35 mph. As with all previous test regimes, measured minimum percent wheel loads are less than the predicted values, probably due to the lack of modeling track roughness. Measured values never fall below 20 percent of the static wheel load.

It is not clear why the results do not match the test data, although inaccuracies in the instrumented wheel sets could account for some of the differences. Another source of error could be the inaccurate modeling of the friction wedges in the truck's vertical and lateral secondary suspension.

It would have been desirable to measure wheel set AOA relative to the track. This would have allowed comparison with the model to determine whether NUCARS is predicting the same truck behavior as occurred during the tests. Unfortunately due to the problems described in Section 3.3.2 attempts to measure AOA failed. The NUCARS model did not appear to predict the attempted flange climbing observed during the tests which caused the AOA measurements to fail. It is therefore likely that the model is not correctly predicting the wheel set AOA, which would lead to an incorrect prediction of the measured L/V ratios. The measured L/V ratios appear too low however to indicate that flange climb was occurring, thus casting doubt on the measured L/V ratio data.

Predicted maximum axle AOA did reach 20 milliradians at some locations in the test zone, as shown in Figure 34. It should be noted that the angles shown in Figure 34 are relative to the normal tangent track and not the deviations caused by the lateral bump. Thus the angles relative to rails are even greater than shown here. These large AOA's imply that the two-dimensional wheel/rail contact geometry files input into NUCARS may be invalid for large AOA's. It may be necessary to use a three-dimensional contact geometry description in order to accurately model these extreme contact conditions.

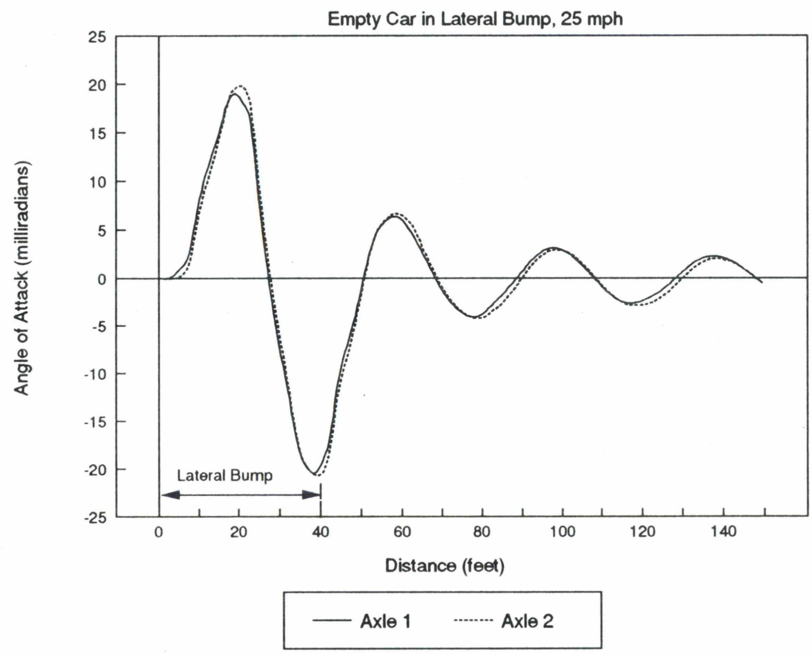

Figure 34. Predicted Axle Angles of Attack for the Empty Car Running at 35 mph in the Single Lateral Bump Test Zone

It is quite likely that at large AOA's, the contact point on the flange is well ahead of the tread contact position. This contact point would then also be fairly high up on the flange. At this position the contact angle between rail and wheel may be less than if the wheel was running with low AOA. If this is the case, the L/V ratio required for flange climb could be much less than would normally be expected.

The loaded car test results shown in Figures 35 through 40 appear to correlate much better with the model predictions. Measured maximum wheel L/V ratios are still less than the predicted values but are much closer and match the general trends predicted by NUCARS. Both test results and model predictions for the trailing axle L/V ratios are higher than the lead axle. Both lead and trail axle results remain below the limiting criteria of 1.0. The maximum axle sum L/V ratios also show the same trends, but the test data is much lower in magnitude than the model predictions. The minimum percent wheel load data also shows reasonable correlation with minimum wheel loads remaining above 40 percent of the static value.

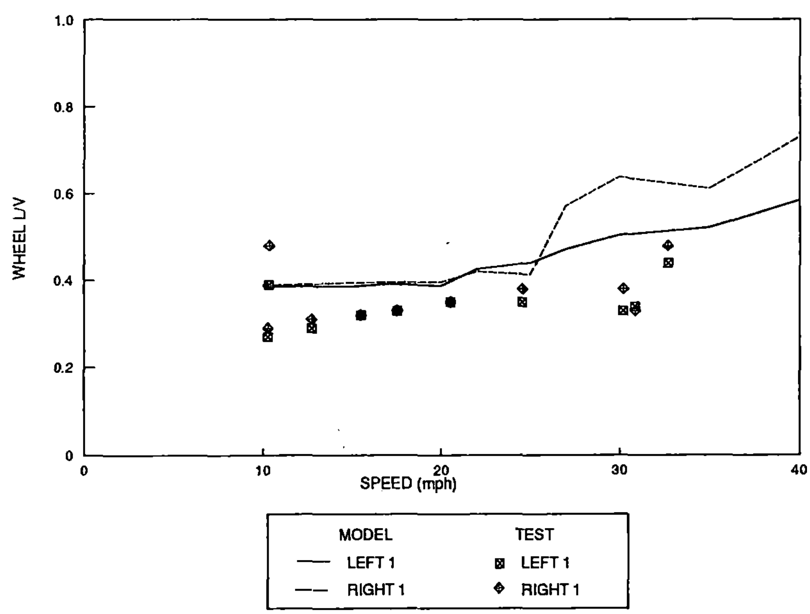

Figure 35. Maximum Wheel L/V Ratios for Axle 1 of the Loaded Car in the Single Lateral Bump Test Zone

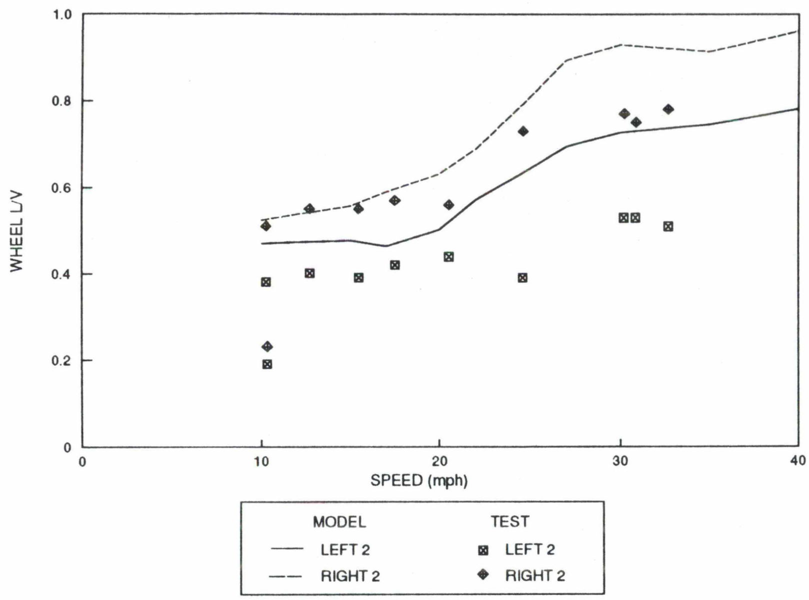

Figure 36. Maximum Wheel L/V Ratios for Axle 2 of the Loaded Car in the Single Lateral Bump Test Zone

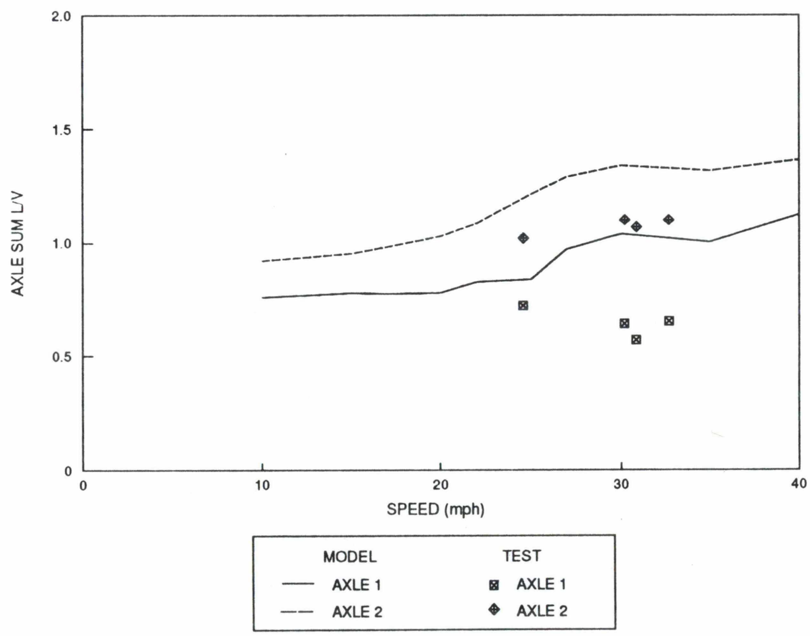

Figure 37. Maximum Axle Sum L/V Ratios for the Loaded Car in the Single Lateral Bump Test Zone

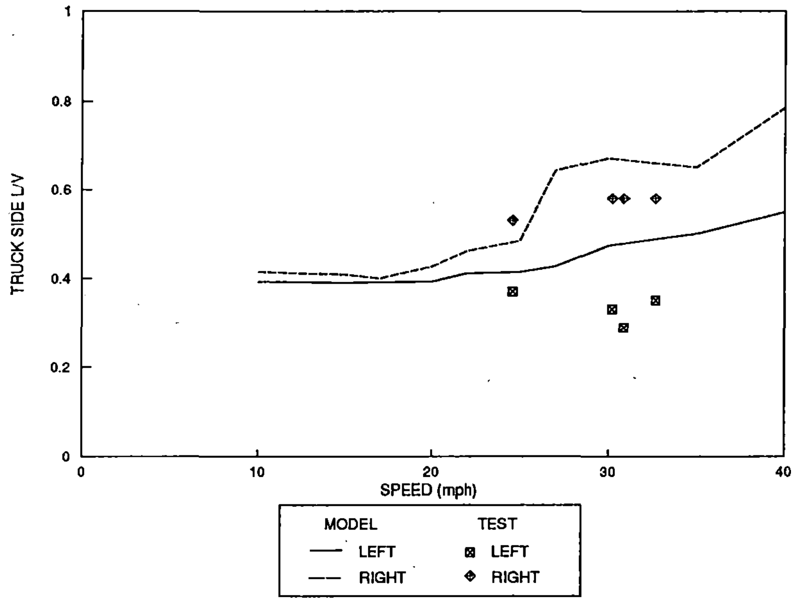

Figure 38. Maximum Truck Side L/V Ratios for the Loaded Car in the Single Lateral Bump Test Zone

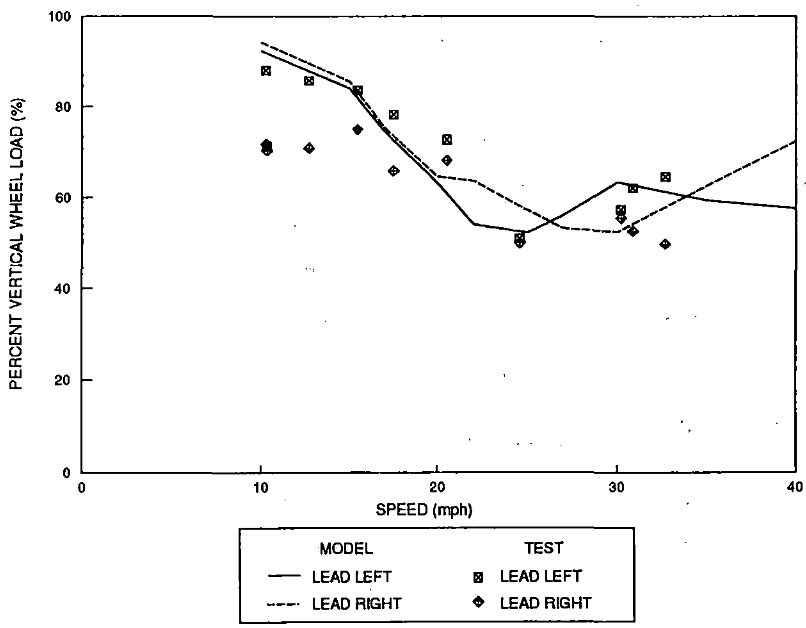

Figure 39. Minimum Percent Wheel Loads for Axle 1 of the Loaded Car in the Single Lateral Bump Test Zone

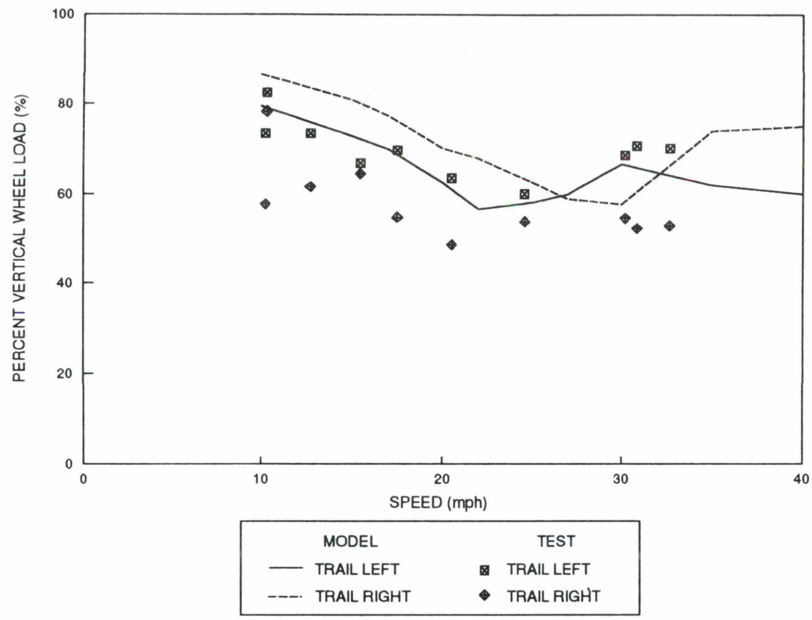

Figure 40. Minimum Percent Wheel Loads for Axle 2 of the Loaded Car in the Single Lateral Bump Test Zone

Although there appears to be reasonable correlation between the model and the test, the test car did exhibit some tendency to flange climb that was not noticed in the model predictions. It is therefore believed that the model predictions could use some improvement. The flange climbing tendency leads to some questions about the L/V data which appear somewhat low for this to be occurring. Only in the case of the right wheel of the rear axle (axle 2) are the values high enough to make this possible. This may imply that the coefficient of friction between the flange and the rail was higher than was measured, or else that the contact angle between wheel flange and rail was less than originally believed.

4.5 <u>SINGLE No. 10 TURNOUT</u>

Figures 41 and 42 are examples of distance histories of the leading outside wheel L/V ratios of the empty and loaded car entering the No. 10 turnout. Test results for the empty car show poor correlation with the model predictions, although the loaded car shows quite good correlation. The empty car data shows particularly poor correlation in the region of the lead-in tangent and the sudden jump in lateral force at the switch point.

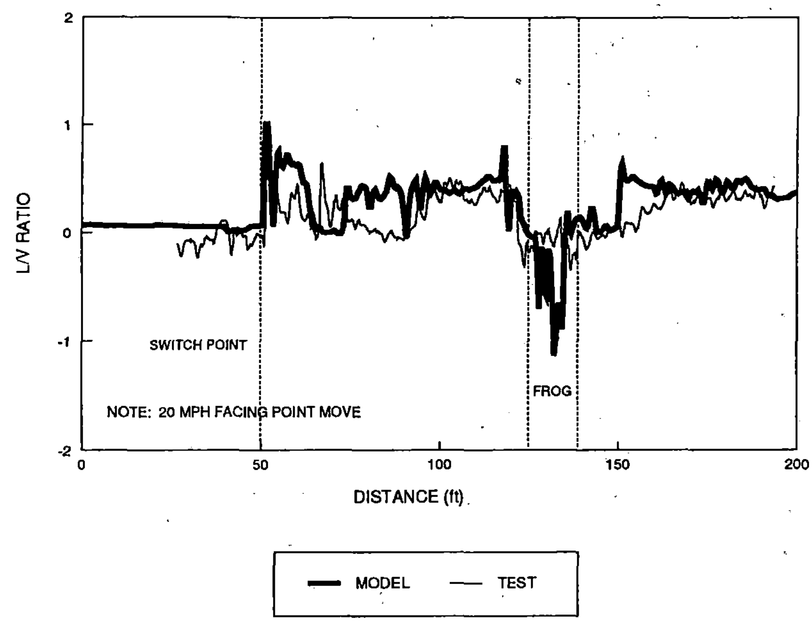

Figure 41. Lead Axle Right (Outside) Wheel L/V Ratios for the Empty Car Entering the No. 10 Turnout

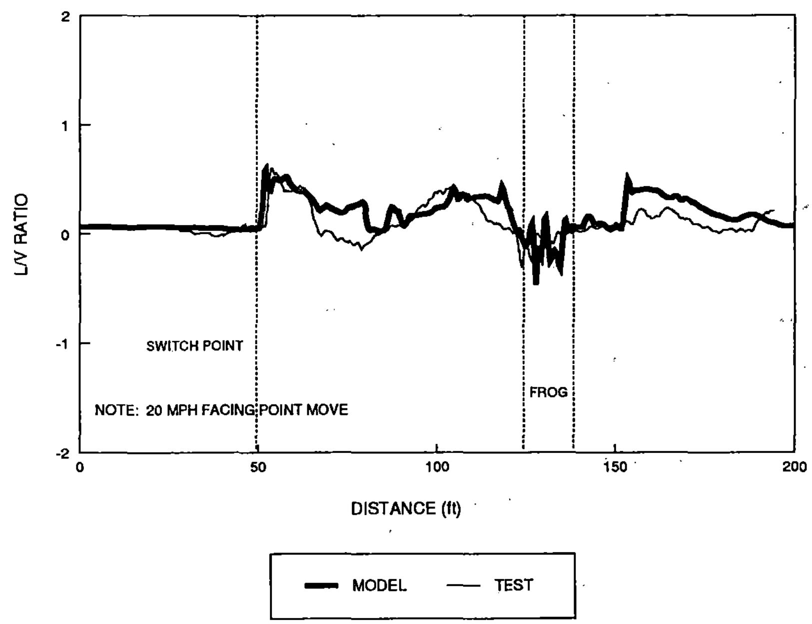

Figure 42. Lead Axle Right (Outside) Wheel L/V Ratios for the Loaded Car Entering the No. 10 Turnout

The lead-in tangent data for the empty car demonstrates one of the problems with the instrumented wheel set data for the empty car. The L/V appears to be negative, indicating an attractive lateral force between the rail and the wheel. This is extremely unlikely. It is believed that for very light vertical loads, there is a negative offset in the lateral force data, probably also acting in combination with the wheel set micro processor having difficulty distinguishing between positive and negative lateral forces. These inaccuracies in the lateral force measurement when combined with the known inaccuracies in the vertical force measurements combine to give very inaccurate L/V ratios.

The trends in plots for both the loaded and empty car are quite clear however. There is a sudden jump in L/V ratio as expected at the switch point, due to the sudden change in the angle of the track relative to the wheels. This L/V ratio falls off along the tangent length of the switch point. The L/V ratio rises again in the curved portion of the closure rails leading up to the frog. At the frog there is a sudden reversal in sign of the L/V ratio. This is because the gage of the track was a bit wide in this location and the backs of the wheel flanges are contacting the wing rails and guard rails. After the frog is a short tangent where the L/V ratios drop to near zero. The model predicts a sudden jump in L/V at the point of change between tangent and the subsequent 8-degree curve. The test data shows a more gradual increase although both settle to similar values in the body of the curve. This discrepancy is probably due to the track having a more gradual transition into the 8-degree curve than was simulated by NUCARS.

This prediction of similar trends for the empty car, and the quite good correlation between test and model for the loaded car is very encouraging. NUCARS has clearly been shown to be a successful tool at predicting performance in turnouts. The use of more accurate descriptions of the turnout geometry and rail cross-sectional geometries would improve these simulations.

To compare the test data with model predictions for the range of speeds tested, statistics of L/V and force values were calculated for the region of the turnout where L/V ratios were highest. The frog area was ignored for this analysis because it is believed that the flange back contact data from both the wheel sets and the NUCARS predictions is suspect.

Figures 43 through 46 compare the maximum wheel, axle sum and truck side L/V ratios for the empty car entering the No. 10 turnout, up to but not including the frog. In general the correlation is not very good, probably for the reasons stated in previous sections. The trends are however similar with a slight increase in L/V with increased speed up to the 20 mph maximum test speed. Model predictions were continued up to 31 mph, when derailment was predicted to occur at the frog.

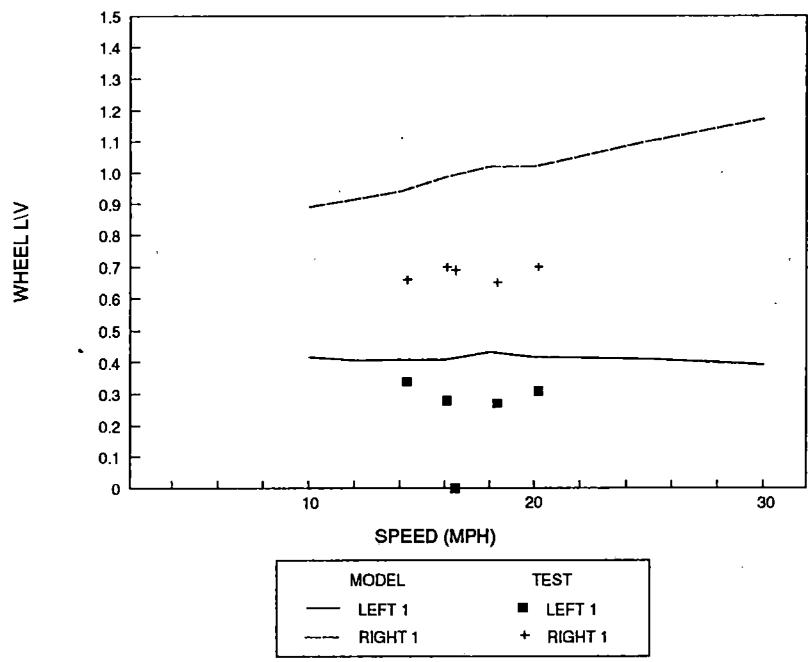

Figure 43. Maximum Wheel L/V Ratios for Axle 1 of the Empty Car Entering the No. 10 Turnout

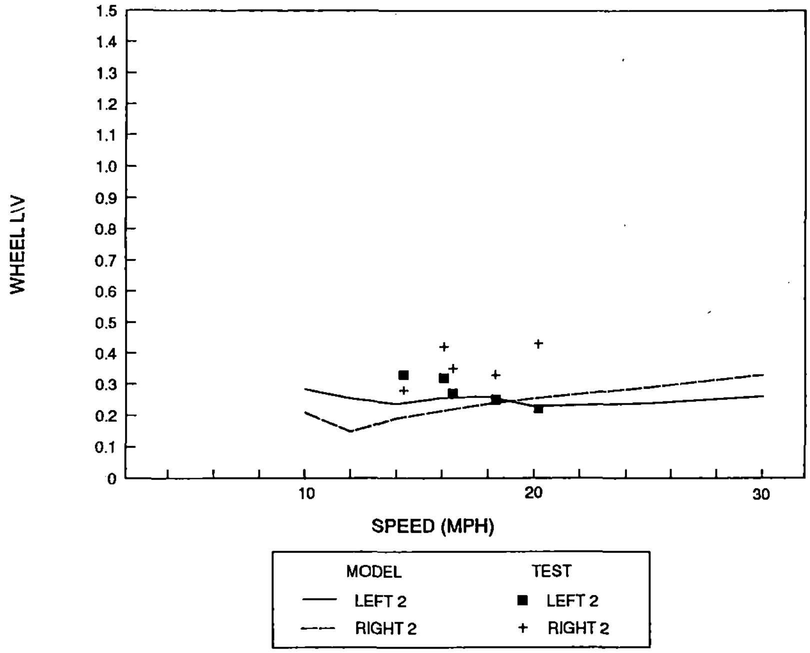

Figure 44. Maximum Wheel L/V Ratios for Axle 2 of the Empty Car Entering the No. 10 Turnout

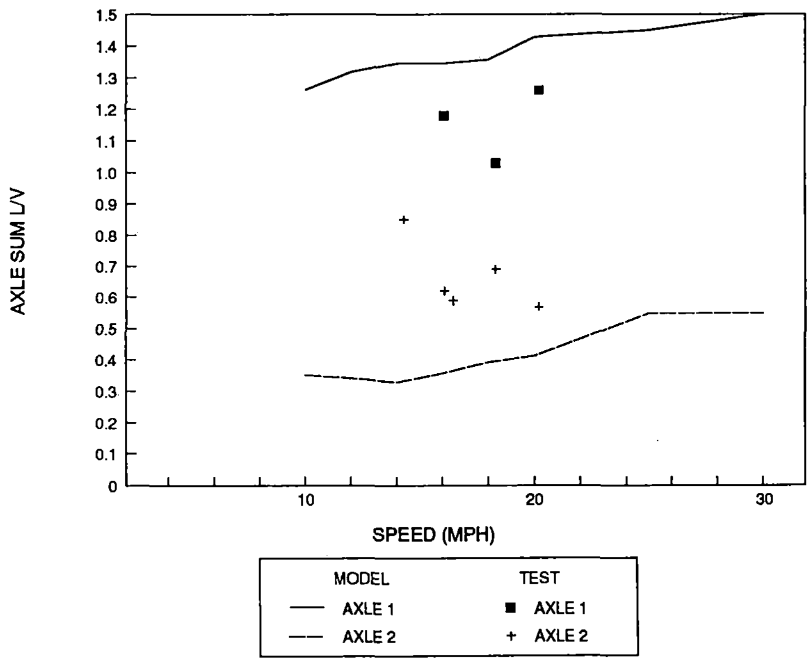

Figure 45. Maximum Axle Sum L/V Ratios for the Empty Car Entering the No. 10 Turnout

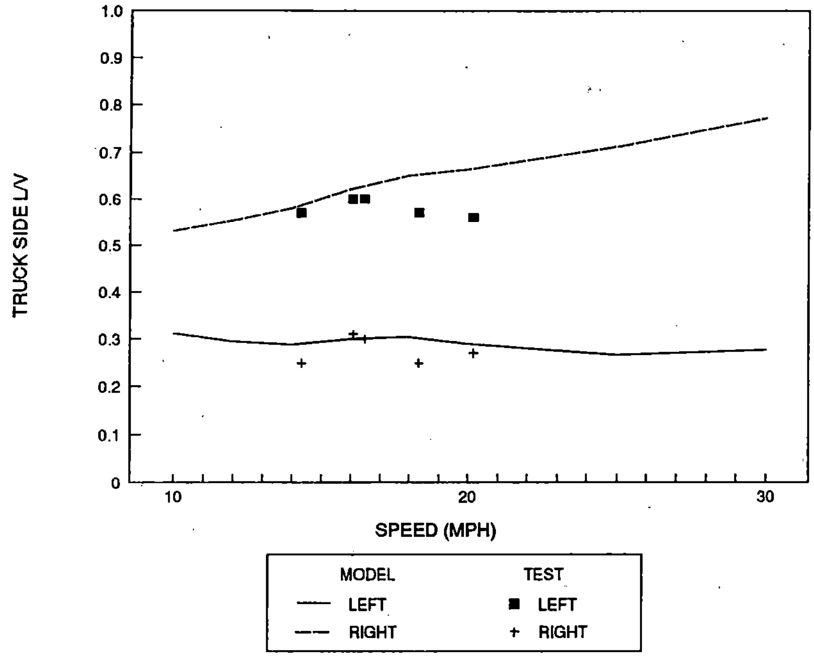

Figure 46. Maximum Truck Side L/V Ratios for the Empty Car Entering the No. 10 Turnout

The Chapter XI safety criteria for maximum wheel L/V were predicted to be exceeded for speeds above 16 mph. The test data does not exceed this criteria. The results of the Lightweight Car 2 project showed that the model usually predicted poorer curving performance for the empty car than actually occurred. It is therefore not surprising that the empty car shows similar disparities in the turnout.

The truck side L/V ratios are also predicted to exceed the Chapter XI criteria of 0.6. This limit is just approached by the test data. The truck side L/V ratio is an indicator of the likelihood of rail rollover. Track in turnouts is usually better restrained against rail rollover than ordinary track. Therefore this exceedence probably does not pose a significant safety concern.

The comparison of measured and predicted performance of the loaded car entering the No. 10 turnout is much better. These results are plotted in Figures 47 through 50. As with the empty car results, the data from the frog portion of the switch are not shown. Up to the 20 mph maximum test speed, no Chapter XI safety criteria are exceeded by the model or the test data. The test data matches model predictions fairly well. The model predicted derailment at the frog at 40 mph.

The normal maximum operating speed through this turnout is limited to 20 mph. The NUCARS predictions indicate the car is operating within safe limits through this turnout in both the empty and loaded condition.

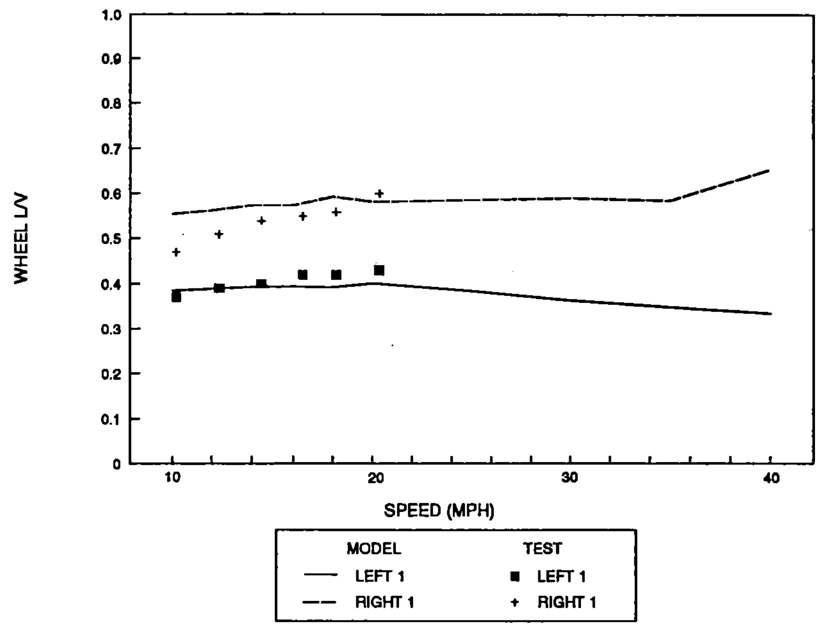

Figure 47. Maximum Wheel L/V Ratios for Axle 1 of the Loaded Car Entering the No. 10 Turnout

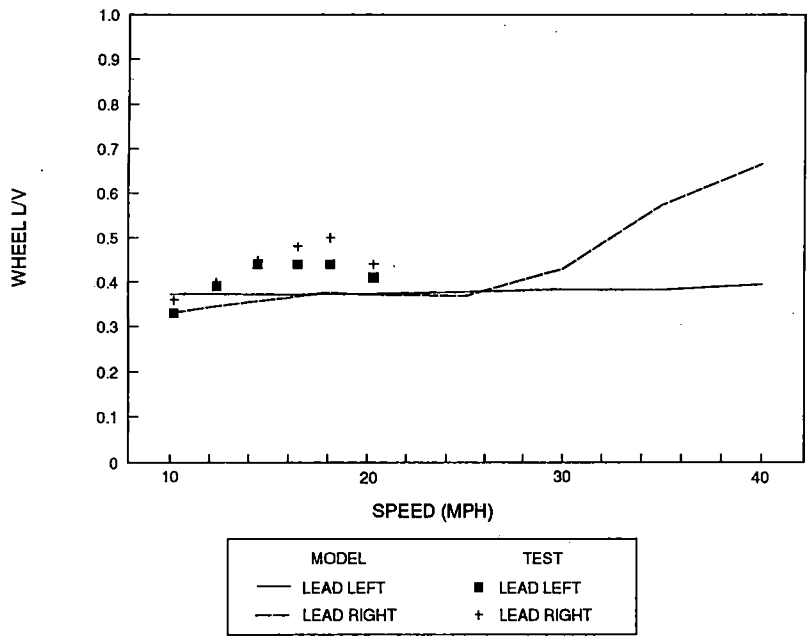

Figure 48. Maximum Wheel L/V Ratios for Axle 2 of the Loaded Car Entering the No. 10 Turnout

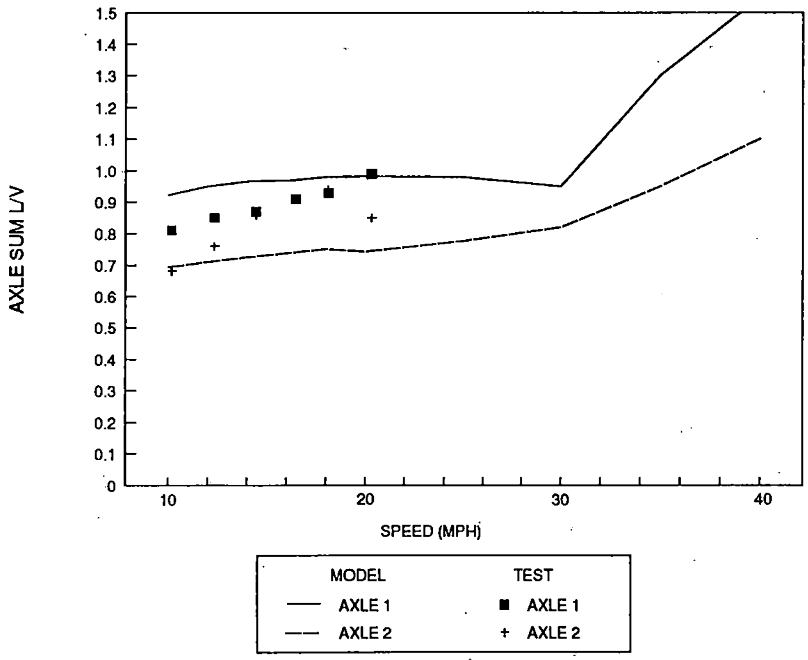

Figure 49. Maximum Axle Sum L/V Ratios for the Loaded Car Entering the No. 10 Turnout

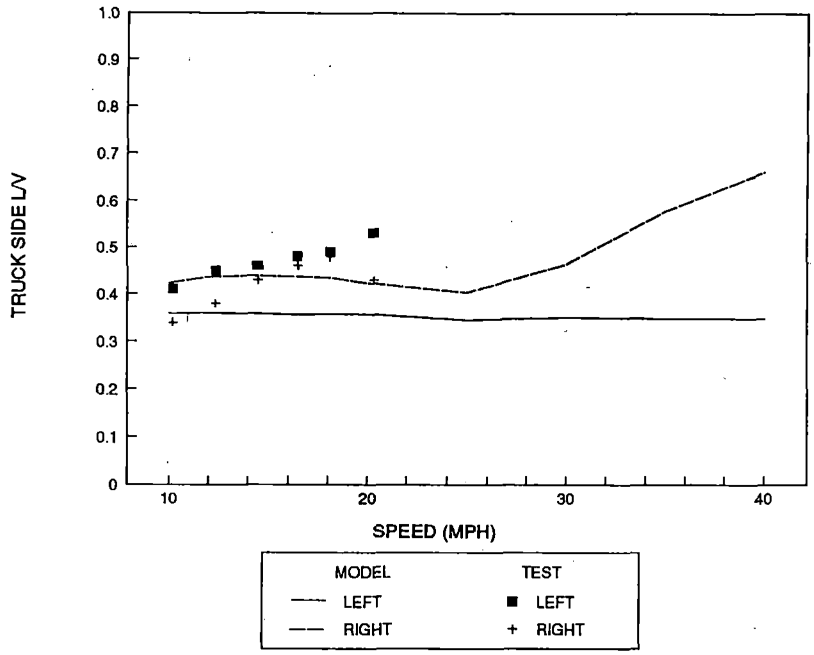

Figure 50. Maximum Truck Side L/V Ratios for the Loaded Car Entering the No. 10 Turnout

4.6 CROSSOVER (TWO No. 15 TURNOUTS BACK TO BACK)

A number of problems were encountered with the NUCARS model of the crossover. Actual measured rail profiles were not available, so design case values were used instead. These design case rail profiles tended to produce two point contact with the measured wheel profiles. This would tend to cause a prediction of poorer performance than a conformal contact profile. It is believed the actual rails are more conformal to the wheels.

The model also consistently predicted derailment at the frogs, probably due to predicted flange back contact with guard and wing rails. To overcome this problem, the wheel/rail profiles in the frog areas were altered to eliminate the guard and wing rail contact. Thus the reversal in sign of the L/V seen in the test data in the frog area is not seen in the NUCARS predictions. Because the modeling of the frog was inaccurate, the modeling was completed only for comparison with the test data. No predictions at higher speed, up to derailment were made. It was believed that the crossover simulation is not yet reliable enough to give a true prediction of derailment.

Comparisons of maximum wheel L/V ratios, axle sum L/V ratios and truck side L/V ratios for the empty car in the No. 15 crossover are shown in Figures 51 through 54. As expected correlation is not very good between the model and the test results. The test data approaches 1.0 at the 35 mph maximum test speed. This was the highest speed allowed for this turnout. The measured truck side L/V exceeds the Chapter XI criteria of 0.6, but as stated in the previous section this is probably not critical due to the stronger track construction in turnouts. The measured axle sum L/V ratios exceed the Chapter XI limit of 1.4 for speeds over 15 mph. These measurements are somewhat doubtful due to the problems of inaccuracy of the lightly loaded instrumented wheel sets. The NUCARS predictions match the trends of the test data, rising with speed.

It is interesting to note that the test data indicates much lower L/Vs for the trailing axle (axle 2) than predicted by the model. This is consistent with previous results showing that the actual car has the trailing axle steering better than in the model.

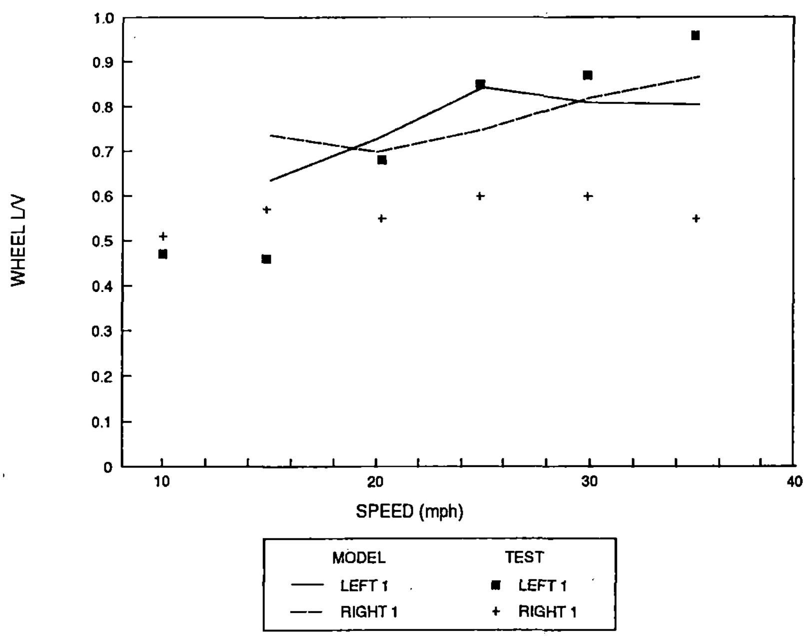

Figure 51. Maximum Wheel L/V Ratio for Axle 1 of the Empty Car in the No. 15 Crossover

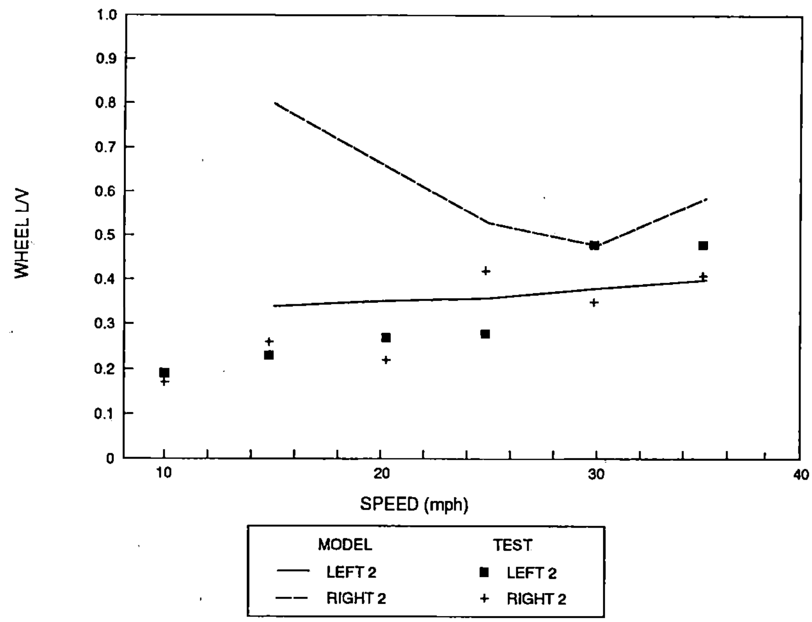

Figure 52. Maximum Wheel L/V Ratios for Axle 2 of the Empty Car in the No. 15 Crossover

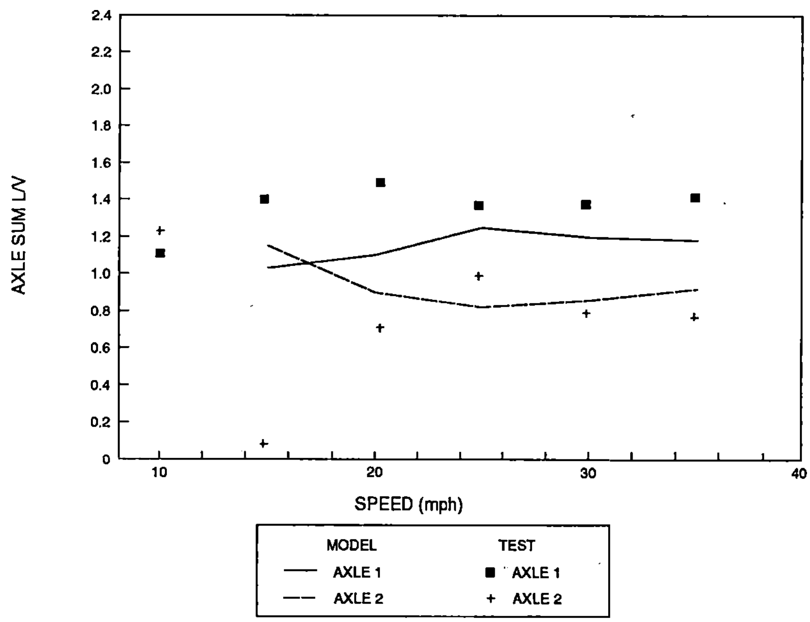

Figure 53. Maximum Axle Sum L/V Ratios for the Empty Car in the No. 15 Crossover

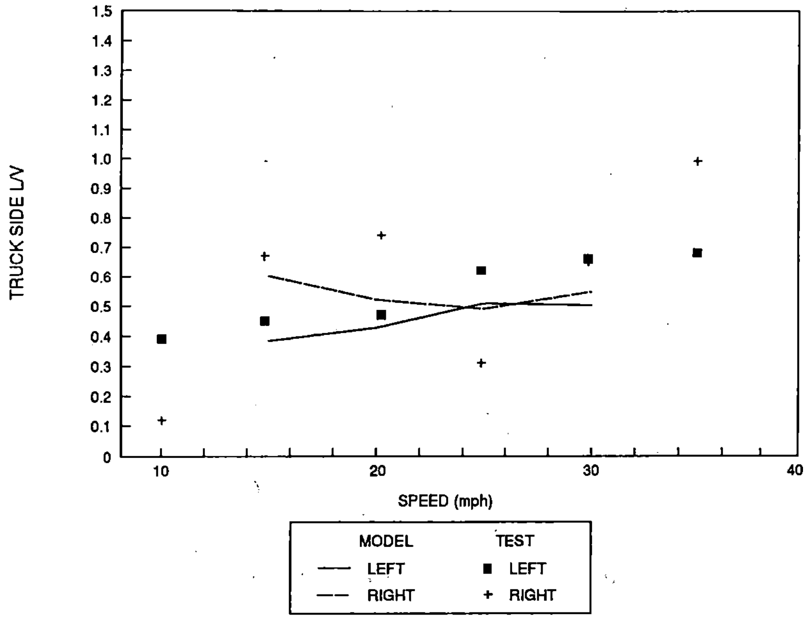

Figure 54. Maximum Truck Side L/V Ratios for the Empty Car in the No. 15 Crossover

Figures 55 and 56 are examples of distance histories for the loaded car negotiating the crossover. The distance histories compare the measured and predicted lead axle L/V ratios for the left and right wheels. The correlation is a little better than for the empty car, but is not as good as for the loaded car in the No. 10 turnout. The peaks at the points are evident, as well as the higher L/Vs caused by negotiating the curved portions of the turnouts.

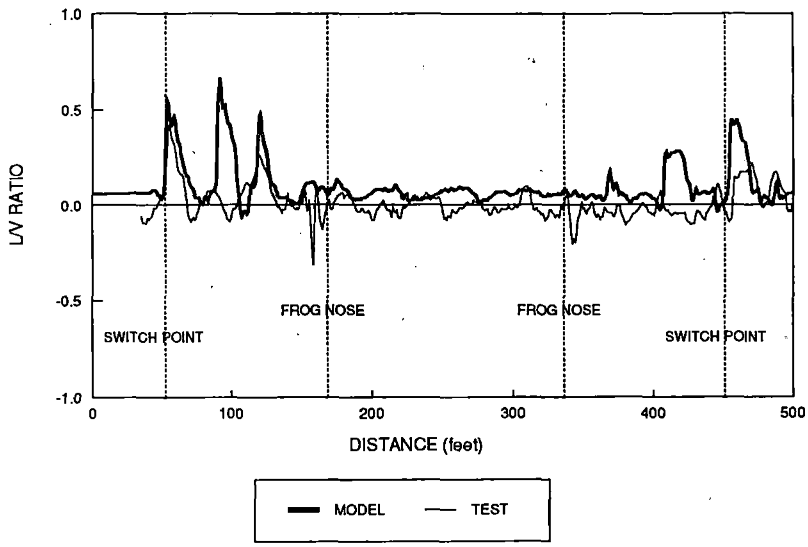

Figure 55. Lead Axle Left Wheel L/V Ratios for the Loaded Car in the No. 15 Crossover

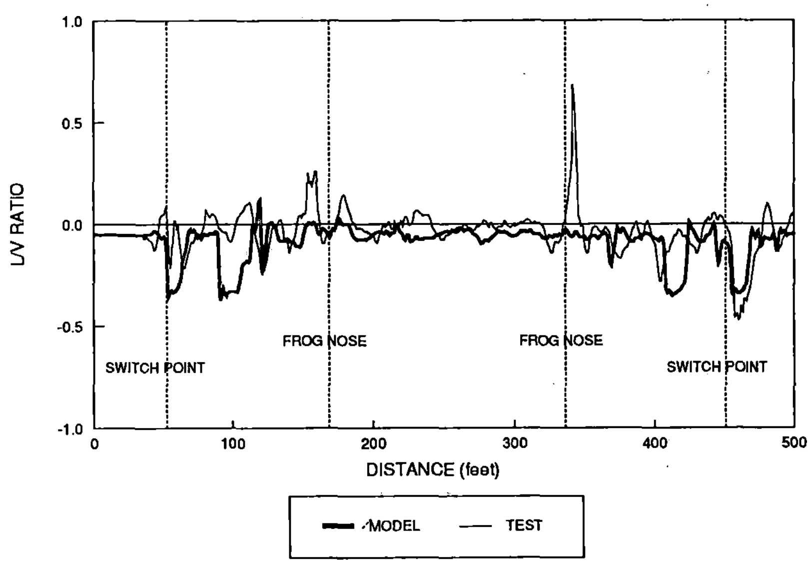

Figure 56. Lead Axle Right Wheel L/V Ratios for the Loaded Car in the No. 15 Crossover

The same problems were encountered modeling the loaded crossover as the empty crossover. This could explain some of the discrepancies between the test and model results. As before the model also consistently predicted derailment at the frogs. Again the wing and guard rails were deleted from the wheel/rail profiles to alleviate this problem. Thus the reversal in sign of the L/V seen in the test data in the frog area is not seen in the NUCARS predictions.

Comparisons of maximum wheel L/V ratios, axle sum L/V ratios and truck side L/V ratios for the loaded car are shown in Figures 57 through 60. In this case the model appears to predict worse performance than the test results. The test data shows no Chapter XI criteria being approached up to the 35 mph maximum test speed. The model shows higher L/Vs throughout the speed range.

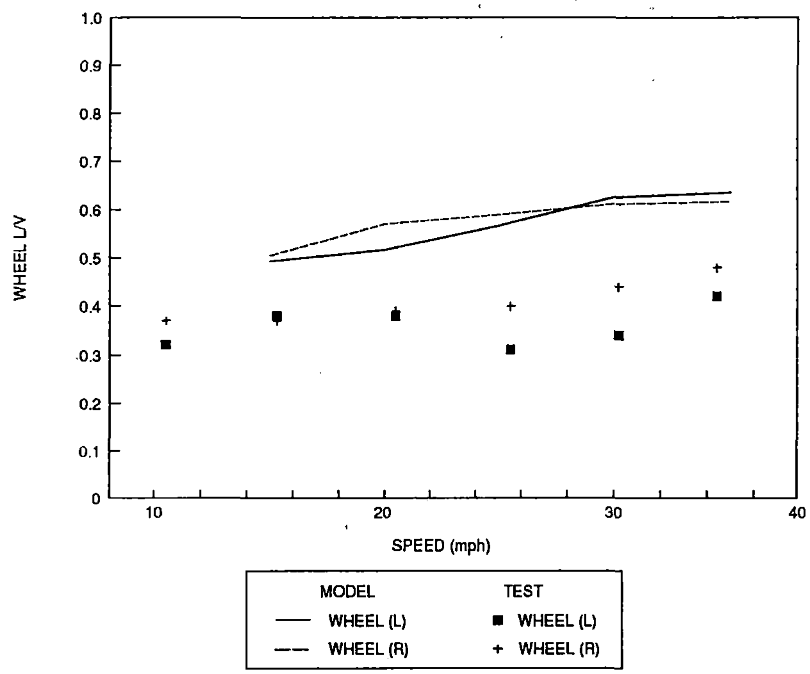

Figure 57. Maximum Wheel L/V Ratios for Axle 1 of the Loaded Car in the No. 15 Crossover

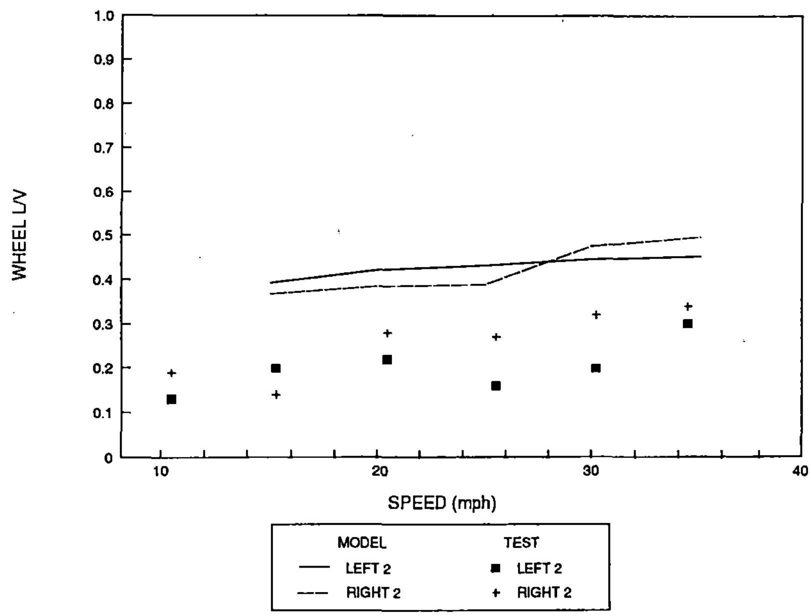

Figure 58. Maximum Wheel L/V Ratios for Axle 2 of the Loaded Car in the No. 15 Crossover

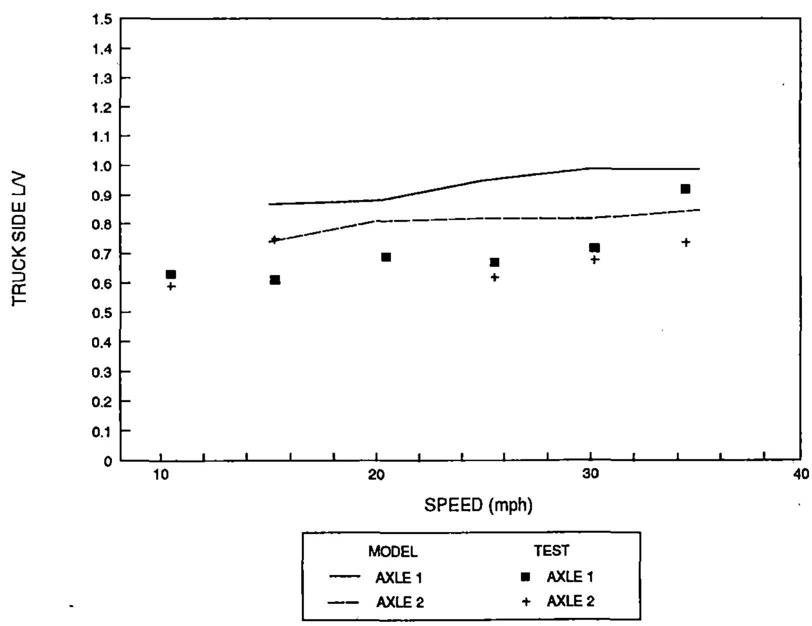

Figure 59. Maximum Axle Sum L/V Ratios for the Loaded Car in the No. 15 Crossover

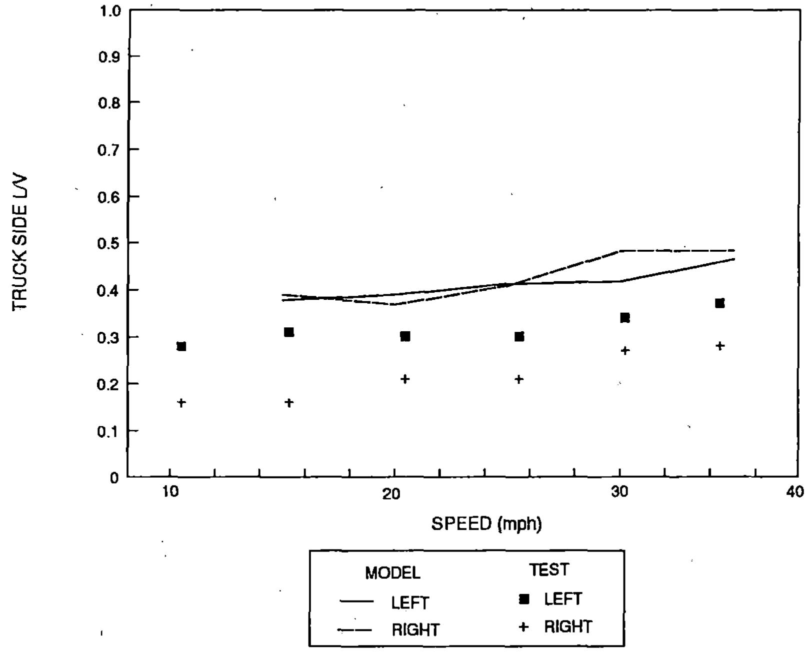

Figure 60. Maximum Truck Side L/V Ratios for the Loaded Car in the No. 15 Crossover

Results are consistent with the hypothesis that the actual rail profiles would be more conformal with the test wheels than the design case values used in the model. They are also consistent with the results of the Lightweight Car 2 curving test results which tended to show better curving performance than was predicted.

5.0 CONCLUSIONS AND RECOMMENDATIONS

5.1 NUCARS MODELING

Good correlation was shown between the model and test data for many of the cases presented, especially for the loaded car. The correlation is much better than for the Lightweight Car 2 research program. This is mostly due to the change in primary shear pad stiffness values used in the NUCARS model as described in Section 3.4. This indicates how sensitive the predicted vehicle performance can be to a minor change in vehicle suspension parameters.

Good correlation gives confidence that for most cases the model can be used to predict vehicle performance for a wide range conditions. Several new test zones were simulated with good success. The only major difficulties were encountered with the modeling of the crossover. Difficulties appear to be related not to the modeling of the car, but to the accuracy of the data used to model the rails in the crossover.

As with the Car 2 research program, the correlation between test and model data was better for the loaded car than the empty car. The main reasons for the empty car showing poorer correlation is the inaccuracy of the instrumented wheel sets in measuring light loads.

Another reason for poor correlation of the empty car simulations is the fact that the suspension is dominated by friction damping. As discovered during the Lightweight Car 2 research program, the method used in the NUCARS model does not thoroughly represent the actions of the friction wedges in the main suspension. This problem is exacerbated for the empty car where the frictional forces are a much greater percentage of the total force acting in the suspension. The latest version of NUCARS now contains more accurate means of representing a variety of friction elements that should improve these results.

NUCARS was also shown to be a successful tool for modeling turnouts. It was obvious however that successful results were highly dependent on the accuracy of the description of the turnout geometry and rail profiles. In general it can be noted that the quality of any simulation is highly dependent on the accuracy of the input data.

Results of the single lateral bump tests indicate a significant area where the NUCARS model could be improved. The use of three dimensional wheel/rail contact geometry data would have provided more accurate predictions. This enhancement to NUCARS is planned for the near future.

Another possible area of improvement would be adding a means of simulating the "surface roughness" of the track. This has been suggested as a reason for discrepancies between test and model results, especially for the minimum wheel loads. This problem was dealt with in the Car 2 research program by utilizing measured track data as input to the NUCARS model. It was not possible to make the same type of measurements for this project. It might be possible to impose some form of random noise signal onto the NUCARS input to simulate track roughness.

5.2 TRACK TESTS

Several new test zones were used for evaluating vehicle performance. The down and out perturbations, particularly the single lateral bump perturbation, produced severe vehicle response, forcing test termination at 30 mph due to wheel lift in the down and out perturbations, and flange climb in the lateral bump perturbation.

The limiting spiral test zone did not produce any severe response, with performance within Chapter XI limits. A slightly modified version of this test zone is now being adopted by the AAR for use in place of the bunched spiral previously specified in Chapter XI.

The turnout and crossover test zones also did not produce very severe response, although performance in the crossover was much better than in the turnout. The turnout did show some exceedence of the Chapter XI limit for truck side L/V. This could be of some concern, not from the aspect of rail rollover, but as an indicator of high forces on the rail fastening systems that could lead to high maintenance requirements in turnouts. The test vehicle used for this project showed good curving performance in the Car 2 research project. A vehicle with worse curving performance would be likely to show worse performance in turnouts.

5.3 PREDICTED LIMITS OF PERFORMANCE

The NUCARS model was used to predict vehicle performance up to the point of derailment for several of the test zones. This serves as an example of using the model to explore the limits of the performance of a vehicle beyond the requirements of Chapter XI.

Results of the Car 2 research program showed that the PSMX-111 test vehicle was unsafe above speeds of 70 mph due to severe hunting oscillations causing derailment. This establishes an absolute upper boundary on speed for this vehicle.

5.3.1 Combined Cross Level and Lateral Perturbations

Wheel lift was shown at 25 and 20 mph for the empty and loaded car respectively, forcing test termination. NUCARS matched these results fairly well, but did not predict derailment from flange climb until above 70 mph. The vehicle is however, in a dangerous operating condition at the lower speeds due to the wheel lift.

5.3.2 Single Lateral Bump

Test results indicated wheel flange climb occurring that was not predicted by the model. Tests were halted at 25 mph for this reason. The model did not predict flange climb up to even 35 mph. It is suspected at this speed the actual car would have already derailed because of flange climb. Therefore, it is believed that the model cannot accurately predict derailment for the test condition. It is suspected that the problem lies with the inaccurate representation of the wheel/rail profiles at large AOA's and not with the NUCARS model itself.

5.3.3 Single No. 10 Turnout

Test results and model predictions showed the vehicle approaching Chapter XI limiting criteria for safe performance at the 20 mph maximum test speed. Derailment was predicted in the frog at 31 mph for the empty car and 40 mph for the loaded car.

5.4 INSTRUMENTATION

Problems were encountered with two important pieces of instrumentation during the tests. These were the axle AOA frames and the instrumented wheel sets.

The AOA frames appeared to give highly inaccurate results in the single lateral bump, probably due to the wheel flanges trying to climb the rails. The ability of NUCARS to accurately model the lateral and yaw behavior of the wheel set is of particular importance. Loss of this data has made it difficult to verify the accuracy of the NUCARS simulations in this area. Development of a better means for measuring AOA would allow more complete validation of NUCARS, especially for situations dominated by lateral inputs.

Instrumented wheel sets used for these tests were susceptible to errors when lightly loaded. In several instances, light loads in combination with large longitudinal forces produced false wheel lift indications. Although these wheel sets were newer and more accurate than those used for the Car 2 research program, they still do not appear accurate enough to meet the requirements of Chapter XI tests for light cars.

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. Handal, Stephen N., "Partial Validation of a Generalized Turnout Model Based on NUCARS," Association of American Railroads Report No. R-797, March 1992.

APPENDIX 1

TEST INSTRUMENTATION REQUIREMENTS

INSTRUMENTATION DATA CHANNEL AND PRESENTATION REQUIREMENTS

Test Name: EXTENDED NUCARS SAFETY EVALUATION, FRA T.O. 42
Work Order: A1B800
Test Engineer: NICHOLAS WILSON

NO./ NAME	MEASUREMENT DESCRIPTION	TRANSDUCER TYPE	EXPECTED RANGE	DIGITAL SAMPLE RATE	FILTER FREQUENCY	COMMENTS/ SPECIAL REQUIREMENTS
LLVF	Lead Left Wheel Vertical Force	PRG Wheel 21a		100 Hz	15 Hz	Lead Truck
LLLF	Lead Left Wheel Lateral Force	PRG Wheel 21a		100 Hz	15 Hz	Lead Truck
LLLV	Lead Left Wheel L/V	PRG Wheel 21a		100 Hz	15 Hz	Lead Truck
LRVF	Lead Right Wheel Vertical Force	PRG Wheel 21b		100 Hz	15 Hz	Lead Truck
LRLF	Lead Right Wheel Lateral Force	PRG Wheel 21b		100 Hz	15 Hz	Lead Truck
LRLV	Lead Right Wheel L/V	PRG Wheel 21b		100 Hz	15 Hz	Lead Truck
LTRQ	Lead Axle Torque	PRG Wheel Set 21		100 Hz	15 Hz	Lead Truck
TLVF	Trail Left Wheel Vertical Force	PRG Wheel 22a		100 Hz	15 Hz	Lead Truck
TLLF	Trail Left Wheel Lateral Force	PRG Wheel 22a		100 Hz	15 Hz	Lead Truck
TLLV	Trail Left Wheel L/V	PRG Wheel 22a		100 Hz	15 Hz	Lead Truck
TRVF	Trail Right Wheel Vertical Force	PRG Wheel 22b		100 Hz	15 Hz	Lead Truck
TRLF	Trail Right Wheel Lateral Force	PRG Wheel 22b		100 Hz	15 Hz	Lead Truck
TRLV	Lead Right Wheel L/V	PRG Wheel 22b		100 Hz	15 Hz	Lead Truck
TTRQ	Trail Axle Torque	PRG Wheel Set 22		100 Hz	15 Hz	Lead Truck
DX1	Lead Truck Left Side Bolster to Body Longitudinal Displacement	String Pot	+/- 5 in.	100 Hz	15 Hz	For truck rotation
DX2	Trail Truck Left Side Bolster to Body Longitudinal Displacement	String Pot	+/- 5 in.	100 Hz	15 Hz	For truck rotation
DX3	Lead Truck Lead Axle Left Bearing Adaptor to Sideframe Longitudinal Displacement	LVDT	+/- 0.5 in.	100 Hz	15 Hz	

INSTRUMENTATION DATA CHANNEL AND PRESENTATION REQUIREMENTS
(Continued page 2 of 3)

DX4	Lead Truck Lead Axle Right Bearing Adaptor to Sideframe Longitudinal Displacement	LVDT	+/- 0.5 in.	100 Hz	15 Hz	
DX5	Lead Truck Trail Axle Left Bearing Adaptor to Sideframe Longitudinal Displacement	LVDT	+/- 0.5 in.	100 Hz	15 Hz	
DX6	Lead Truck Trail Axle Right Bearing Adaptor to Sideframe Longitudinal Displacement	LVDT	+/- 0.5 in.	100 Hz	15 Hz	
DY1	Lead Truck Lead Axle Left Bearing Adaptor to Sideframe Lateral Displacement	LVDT	+/- 0.5 in.	100 Hz	15 Hz	
DY2	Lead Truck Lead Axle Right Bearing Adaptor to Sideframe Lateral Displacement	LVDT	+/- 0.5 in.	100 Hz	15 Hz	
DY3	Lead Truck Trail Axle Left Bearing Adaptor to Sideframe Lateral Displacement	LVDT	+/- 0.5 in.	100 Hz	15 Hz	
DY4	Lead Truck Trail Axle Right Bearing Adaptor to Sideframe Lateral Displacement	LVDT	+/- 0.5 in.	100 Hz	15 Hz	
DY5	Lead Truck Left Front Bolster to Sideframe Lateral Displacement	String Pot	+/- 2 in.	100 Hz	15 Hz	With DY6 measures bolster to left sideframe yaw
DY6	Lead Truck Left Rear Bolster to Sideframe Lateral Displacement	String Pot	+/- 2 in.	100 Hz	15 Hz	With DY5 measures bolster to left sideframe yaw
DY7	Lead Truck Right Front Bolster to Sideframe Lateral Displacement	String Pot	+/- 2 in.	100 Hz	15 Hz	With DY8 measures bolster to right sideframe yaw
DY8	Lead Truck Right Rear Bolster to Sideframe Lateral Displacement	String Pot	+/- 2 in.	100 Hz	15 Hz	With DY7 measures bolster to right sideframe yaw
DZ1	Lead Truck Left Spring Vertical Displacement	String Pot	+/- 5 in.	100 Hz	15 Hz	
DZ2	Lead Truck Right Spring Vertical Displacement	String Pot	+/- 5 in.	100 Hz	15 Hz	
DZ3	Trail Truck Left Spring Vertical Displacement	String Pot	+/- 5 in.	100 Hz	15 Hz	

INSTRUMENTATION DATA CHANNEL AND PRESENTATION REQUIREMENTS (Continued page 3 of 3)						
DZ4	Trail Truck Right Spring Vertical Displacement	String Pot	+/- 5 in.	100 Hz	15 Hz	
DZ5	Lead Truck Left Side Bolster to Body Vert Displacement	String Pot	+/- 5 in.	100 Hz	15 Hz	With DZ6 measures bolster to body roll
DZ6	Lead Truck Right Side Bolster to Body Vert Displacement	String Pot	+/- 5 in.	100 Hz	15 Hz	With DZ5 measures bolster to body roll
AY1	Lead Truck Lead Axle Lateral Acceleration	Accelerometer	+/- 5 g.	100 Hz	15 Hz	
AY2	Lead Truck Trail Axle Lateral Acceleration	Accelerometer	+/- 5 g.	100 Hz	15 Hz	
AY3	Trail Truck Lead Axle Lateral Acceleration	Accelerometer	+/- 5 g.	100 Hz	15 Hz	
AY4	Trail Truck Trail Axle Lateral Acceleration	Accelerometer	+/- 5 g.	100 Hz	15 Hz	
AY5	Lead Body Bolster Lateral Acceleration	Accelerometer	+/- 5 g.	100 Hz	15 Hz	
AY6	Trail Body Bolster Lateral Acceleration	Accelerometer	+/- 5 g.	100 Hz	15 Hz	
RG1	Lead End Roll Angle	Roll Gyro	+/- 10 deg.	100 Hz	15 Hz	
RG2	Trail End Roll Angle	Roll Gyro	+/- 10 deg.	100 Hz	15 Hz	
LWHL	Left Wheel Lateral Position	Video Wheel Rail Contact System		100 Hz	15 Hz	Analog Output from Video System
RWHL	Right Wheel Lateral Position	Video Wheel Rail Contact System		100 Hz	15 Hz	Analog Output from Video System
LRAL	Left Rail Lateral Position	Video Wheel Rail Contact System		100 Hz	15 Hz	Analog Output from Video System
RRAL	Right Rail Lateral Position	Video Wheel Rail Contact System		100 Hz	15 Hz	Analog Output from Video System

NOTES:

1. Lead end is A end. Lead truck will have the majority of the instrumentation, including video wheel/rail contact measurement system.
2. Instrumented wheels to be placed with least worn wheels on lead axle. A wheel on left side, B wheel on right side.
3. Brackets for most instruments already in place on truck from previous tests.
4. DY5, DY6, DY7, DY8 can be mounted on beams on the ends of the bolster in the same manner as for the Truck Performance test (Curt Urban's work order B1B100). Inboard mounting is also acceptable.
5. Video wheel/rail contact system currently under development. Current system only updates analog output 5 times per second. Video images to be recorded on tape for further development work.
6. Three wayside angle of attack measurement frames required for tests in the single lateral perturbation.