LIGHTWEIGHT CAR SIMULOADER TEST

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by

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13. Abstract

Railcars experience fatigue damage from loads encountered during in-train revenue service operation. In 1984, the Federal Railroad Administration (FRA) acquired an electro-hydraulic shaker system that allowed railcar fatigue performance to be investigated at the Transportation Test Center, Pueblo, Colorado. The system, known as the Simuloader, was donated to the FRA by the Union Tank Car Company and re-creates truck bolster motions and longitudinal coupler forces.

Testing conducted in 1986 focused on validating the Simuloader's ability to replicate desired environments, including on-track induced vibrations and motions introduced into a railcar by another shaker system. The tests were performed on an intermodal railcar designed to transport single highway trailer units.

The following conclusions were drawn from the course of testing.

- Techniques developed previously for obtaining inputs for the Vibration Test Unit (VTU) can be used to generate inputs for the Simuloader.
- The Simuloader was able to invoke car body responses similar to responses when testing on the VTU.
- The Simuloader was found to excite test car responses with and without its suspension in a manner similar to responses encountered on-track. With practice and experimentation, differences in response amplitudes can and have in subsequent test programs, be reduced to acceptable, minimal levels.

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EXECUTIVE SUMMARY

Railcars experience fatigue damage from loads encountered during in-train revenue service operation. In 1984, the Federal Railroad Administration (FRA) acquired an electro-hydraulic shaker system that allowed railcar fatigue performance to be investigated at the Association of American Railroads (AAR), Transportation Test Center (TTC), Pueblo, Colorado.

The system, known as the Simuloader, was donated to the FRA in 1984 by the Union Tank Car Company and was delivered thereafter to the TTC. FRA and TTC agreed that the FRA would fund the delivery and installation of the Simuloader, and the AAR would fund its initial testing. Testing was completed in 1986.

The Simuloader re-creates truck bolster motions and longitudinal coupler forces. Initial testing focused on validating the Simuloader's ability to replicate desired environments, including on-track induced vibrations and motions introduced into a railcar by another shaker system. The tests were performed on an intermodal railcar designed to transport single highway trailer units. The test car was equipped with a leaf-spring type suspension/single-axle combination located at each end of a skeletonized frame.

The program's objectives were to validate the Simuloader's capability for re-creating, or simulating, railroad environment, and to discover the similarities between it and another shaker system -- the Vibration Test Unit (VTU).

From testing, the following conclusions were drawn:

- Techniques developed previously for obtaining inputs for the VTU can be used to generate inputs for the Simuloader.
- The Simuloader was able to invoke car body responses similar to responses when testing on the VTU.
- The Simuloader was found to excite test car responses with and without its suspension in a manner similar to responses encountered on-track. With practice and experimentation, differences in response amplitudes can, and have in subsequent test programs, be reduced to acceptable, minimal levels.

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1.0 BACKGROUND

Railcars experience fatigue damage from loads encountered during in-train revenue service operation. In 1984, the Federal Railroad Administration (FRA) acquired an electrohydraulic shaker system that allowed railcar fatigue performance to be investigated at the Association of American Railroads (AAR), Transportation Test Center (TTC), Pueblo, Colorado.

The system, known as the Simuloader, was donated to the FRA in 1984 by the Union Tank Car Company and was delivered thereafter to the TTC. FRA and TTC agreed that the FRA would fund the delivery and installation of the Simuloader, and the AAR would fund its initial testing. Testing was completed in 1986.

The Simuloader re-creates truck bolster motions and longitudinal coupler forces. The testing conducted in 1986 focused on validating the Simuloader's ability to replicate desired environments, including on-track induced vibrations and motions introduced into a railcar by another shaker system. The tests were performed on an intermodal railcar designed to transport single highway trailer units. The test car was equipped with a leaf-spring type suspension/single-axle combination located at each end of a skeletonized frame.

Due to the time difference between testing and documentation, in several cases, appropriate data was not presented in this report due to data storage tape integrity failure. However, the 1986 test data is presented when possible.

2.0 OBJECTIVES

The following objectives were met during this program:

(1) Similarities between the Simuloader system and another shaker system -- the Vibration Test Unit (VTU) -- were investigated.

(2) Validation of the Simuloader's capabilities for re-creating (simulate) railroad environment was obtained. The verification was made for testing with and without the test car's suspension.

3.0 METHODOLOGY

The project included the following main tasks:

- Preparation and execution
- Data collection of the load environment in the field for the single-axle vehicle
- Modifications to the Simuloader to accept a single-axle vehicle with and without the car's suspension
- Input profile preparation for Simuloader excitation signals
- Testing the vehicle on the Simuloader with and without the car's suspension
- Data analysis to determine how well the responses of the vehicle on the Simuloader compares with the response data from on-track and VTU tests

4.0 TEST CAR

The tests were performed on an intermodal railcar designed to transport single highway trailer units. The test car was equipped with a leaf-spring type suspension/single-axle combination located at each end of a skeletonized frame consisting of a center sill, end sills, suspension support structure and tire platforms. The car was 50 feet 6 inches long over the end sills, with a truck center distance of 36 feet 6 inches.

5.0 ON-TRACK TESTS TO OBTAIN LOAD ENVIRONMENT

The main purpose of the on-track test was to acquire input data for the Simuloader. A secondary purpose of the on-track test was to obtain response data from the trailer and car body.

5.1 INSTRUMENTATION

The technique utilized to develop inputs for the Simuloader testing on the car, with the car's suspension, involved collecting axle acceleration data to be subsequently converted into drive-signal displacement data. Car body accelerations were recorded as a means to excite the test car body without its suspension. Other measurements were recorded to meet the first objective of verifying that the Simuloader could replicate the railroad environment. Similar measurements also were made during previous testing on the VTU, thus achieving the second program objective by allowing the similarities of the Simuloader and VTU to be evaluated. Details of testing on the VTU, which differs from the Simuloader in that it is designed specifically to input excitation only through the wheels of railcars, are presented in FRA report No. FRA/ORD-88/07, *Safety Aspects of New and Untried Freight Cars.* Only selected results to compare to Simuloader test results are presented in this report.

The data from the on-track test was recorded using a telemetry/PCM system. The data was low pass filtered at 30 Hz and digitally sampled at 150 samples per second. Twenty-one channels of data were acquired digitally. In addition, fourteen accelerometers were mounted on various locations on the flatcar body and recorded with a Kiowa analog tape recorder. This data was recorded for the development of car body inputs for Simuloader tests without the car's suspension. Figure 1 is a sketch showing the locations of the measurements.

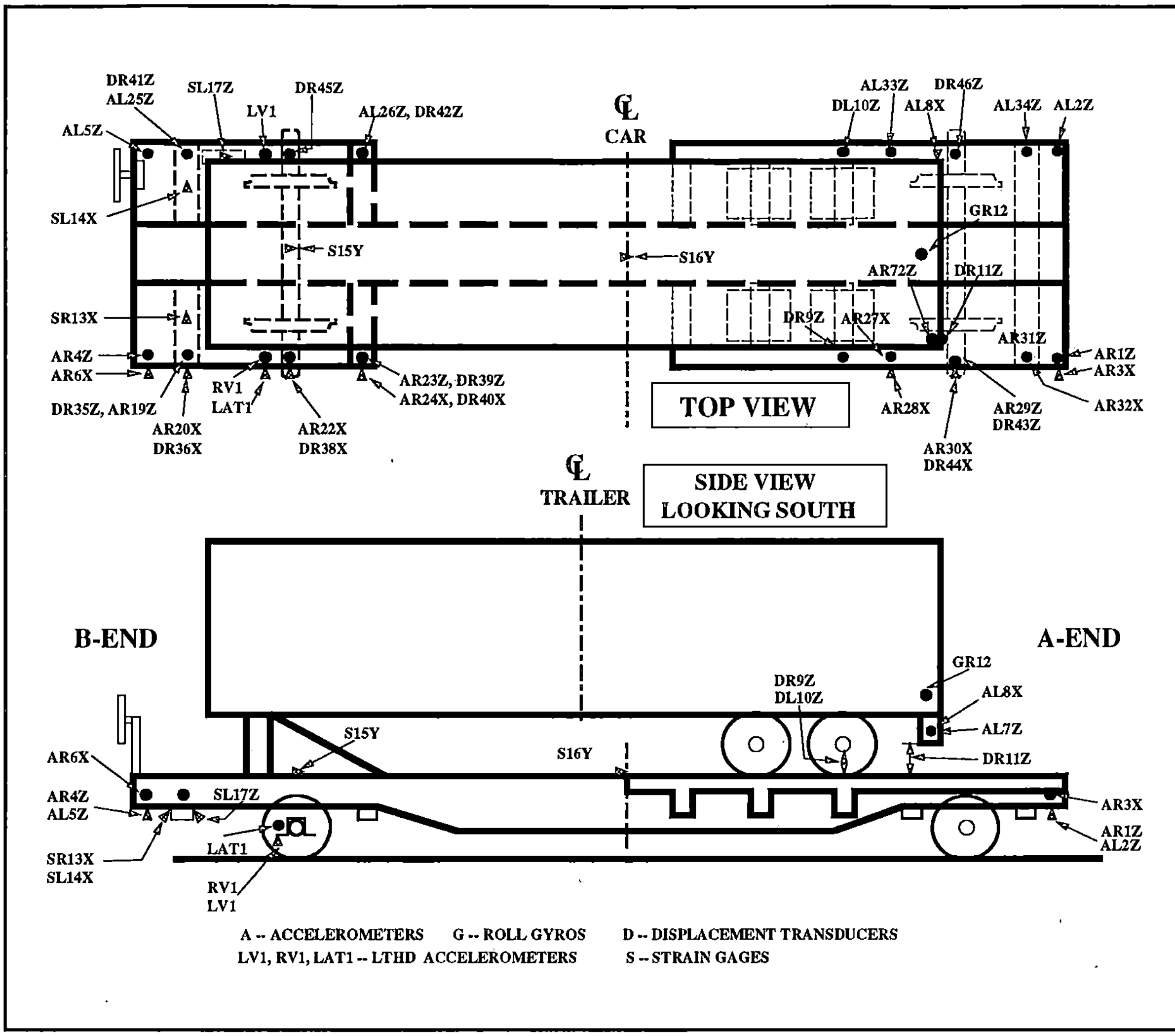

Figure 1. Instrumentation Locations

5.2 TESTS TO OBTAIN LOAD ENVIRONMENT INFORMATION

On-track tests were performed in May and June, 1986. Class 5 track, located at TTC on the Railroad Test Track, was traversed at 30, 40, and 50 mph. Class 2 track tests were performed at the nearby Pueblo Depot Activity (PDA) at 15 and 20 mph. In addition, two perturbed sections of track located at TTC, twist-and-roll and yaw-and-sway, were included as test sections. Figure 2 is a schematic overview of the sections of track used to test the railcar.

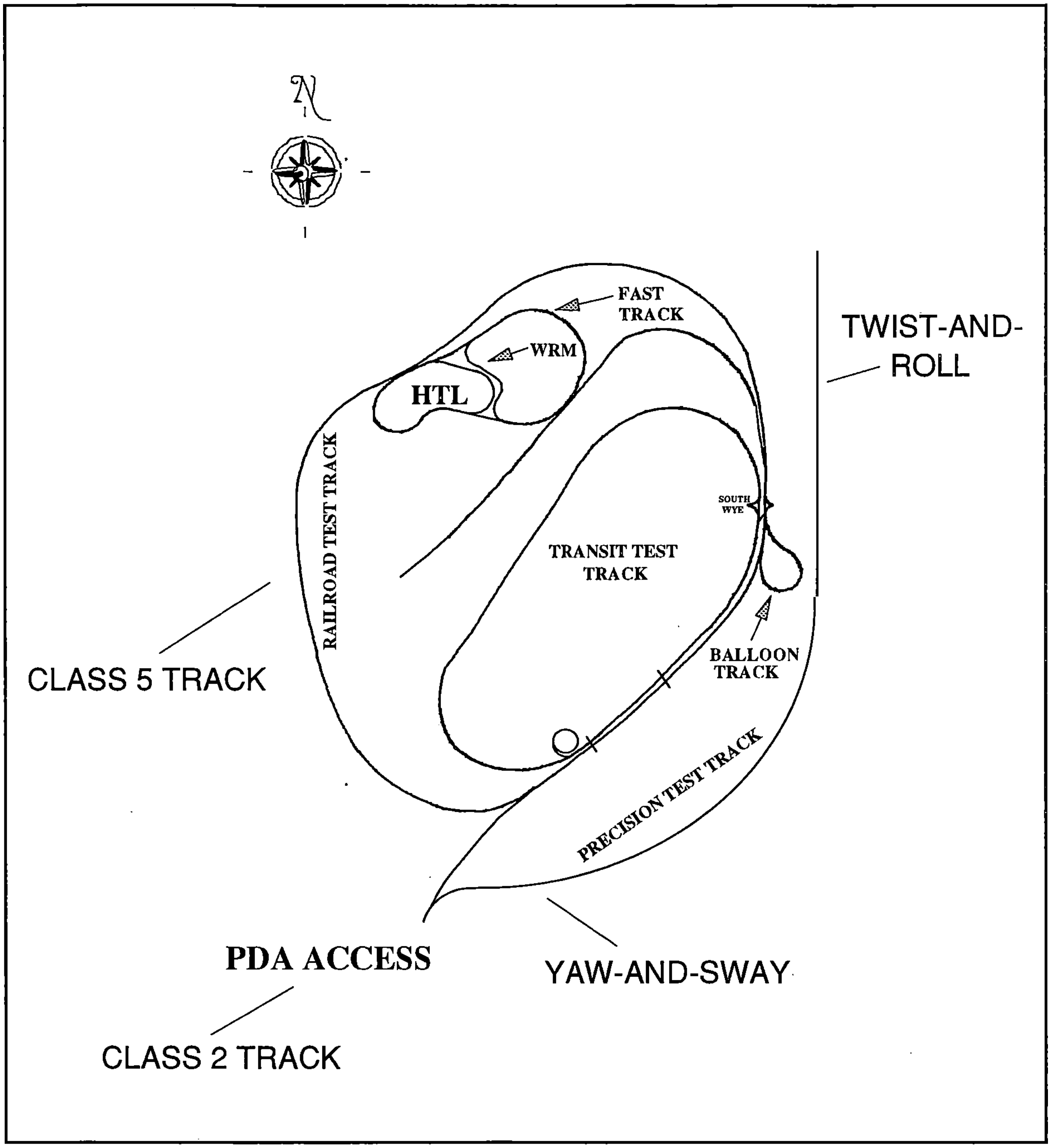

Figure 2. TTC Test Facilities

The tests on twist-and-roll track, conducted at 15, 20, and 30 mph, determined the car's ability to negotiate cross level perturbations. These perturbations, which may be found in locations where rail joints are staggered 90 degrees out-of-phase, were designed to excite the natural twist-and-roll motions of the car. The twist-and-roll test section was shimmed to represent staggered-jointed rail with a cross level of 0.75 inches at 39-foot intervals (Figure 3).

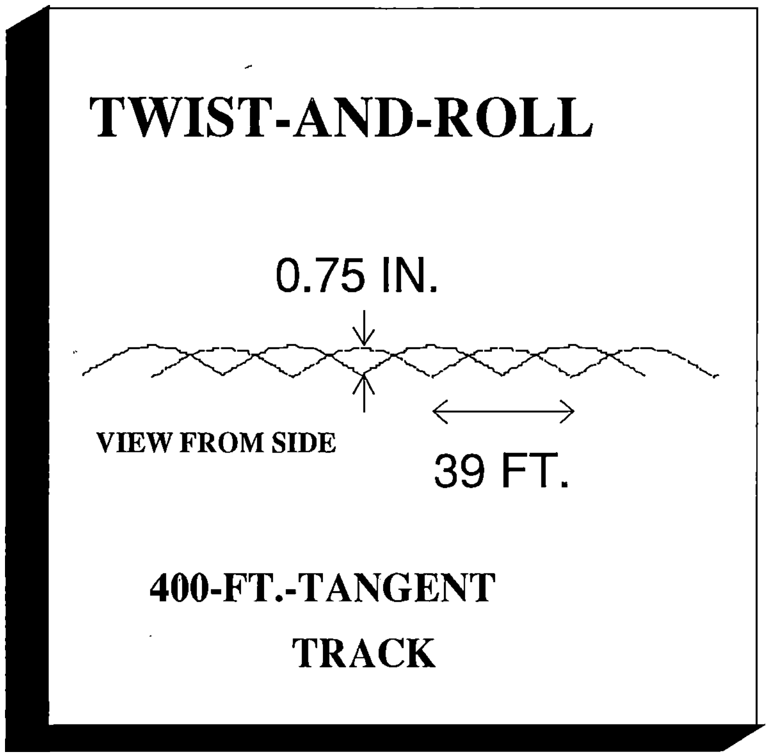

Figure 3. Twist-and-Roll Test Zone

The tests on yaw-and-sway track perturbations, conducted at 15 and 20 mph, determined the ability of the car to negotiate laterally misaligned track. Track with perturbations of this type may be found where the underlying ground is unstable and allows the track to shift in the lateral direction. The yaw-and-sway test section has sinusoidal track alignment deviations of 39-foot wavelength with an amplitude of 1.25 inches peak-to-peak on both rails. A constant wide gage of 57.5 inches is maintained in this test zone. Figure 4 displays the yaw-and-sway perturbation layout.

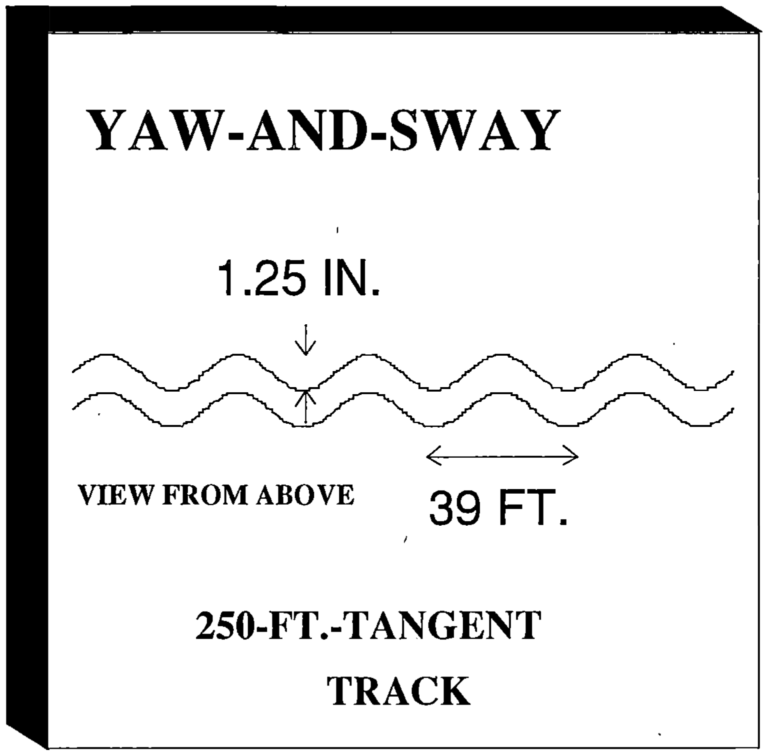

Figure 4. Yaw-and-Sway Test Zone

5.3 ON-TRACK TEST DATA ANALYSIS AND RESULTS

The main purpose of the on-track tests was to obtain test data for the development of Simuloader inputs and corresponding response data to allow comparisons of on-track test responses to Simuloader test responses. This section will present results of measurements processed with the Simuloader excitation input development procedure. The comparisons of on-track responses to Simuloader test responses are made in Section 6.4.2.

5.3.1 Inputs for Simuloader Tests on Car with Suspension

The Locomotive Track Hazard Detection (LTHD) system was used to acquire measurements for developing inputs to test the car with its suspension on the Simuloader. The LTHD system was designed to locate significant track geometry defects. It can also be used to produce vertical and lateral space profiles describing wheel set motion. This equipment has been used frequently to obtain representative track input profiles for the VTU.

The LTHD method involves collecting lateral and vertical accelerations for each axle with servo-accelerometers. The accelerometers are packed in boxes with a dense foam packing material to protect them from high-frequency mechanical vibrations.

The acceleration signals are low-pass filtered and collected in digital form. Using software, the acceleration data is converted into vertical and lateral wheel set displacements. This conversion is done with a double-integration routine, which corrects for angular and gravitational effects, phase distortion, and signal noise before integrating.

The input development procedure for testing with the car's suspension resulted in time histories of left- and right-wheel vertical displacements, and wheel set lateral displacements. The histories were obtained with the LTHD hardware (measurements LV1, RV1, and LAT1 in Figure 1) and processing system for Class 2, twist-and-roll, and yaw-and-sway track. Figures 5 and 6 display time histories and power spectral densities (PSD's) of Class 2 left and right vertical wheel displacements, and lateral axle displacements. Figures 7 and 8 display time histories for twist-and-roll and yaw-and-sway track sections.

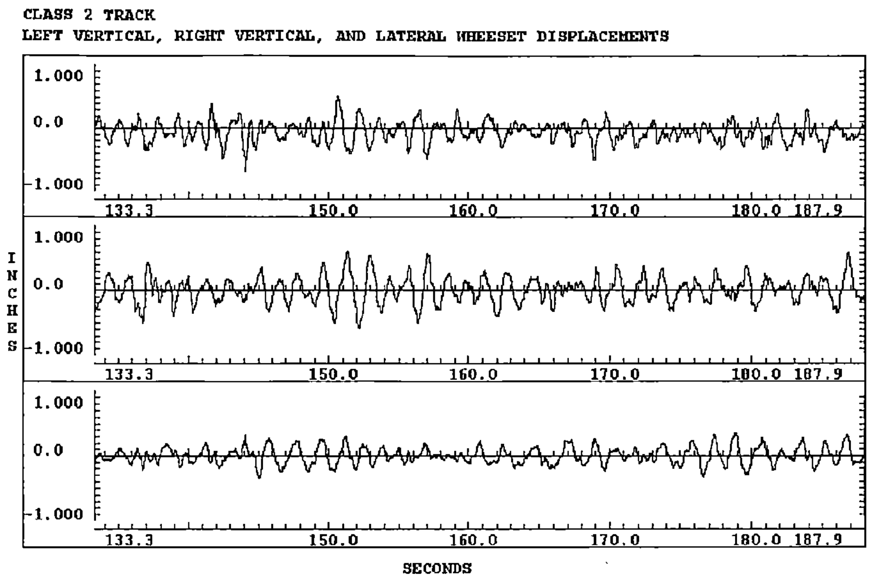

Figure 5. Time Histories of Left and Right Wheel Vertical Displacements, Lateral Axle Displacement Obtained from Testing on Class 2 Track

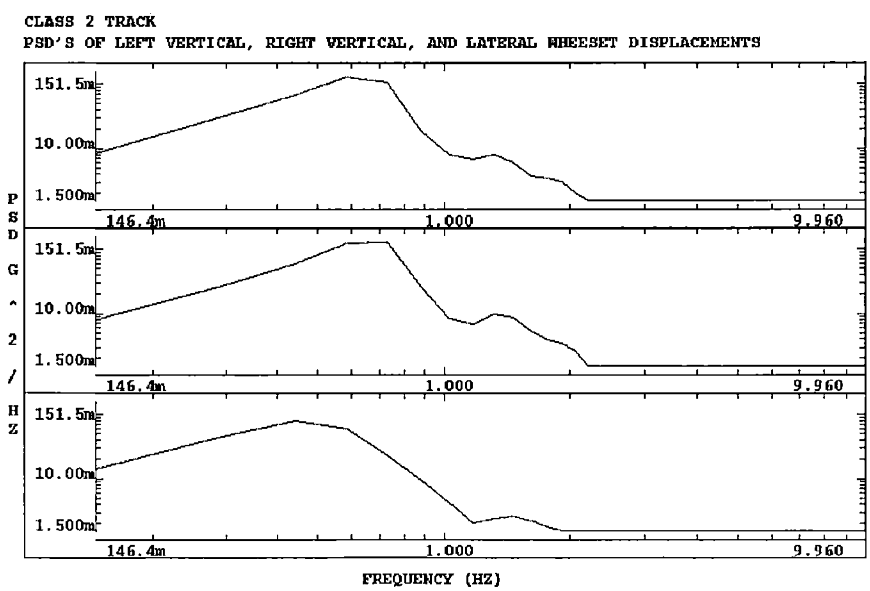

Figure 6. PSD's of Left and Right Wheel Vertical Displacements, Lateral Axle Displacement Obtained from Testing on Class 2 Track

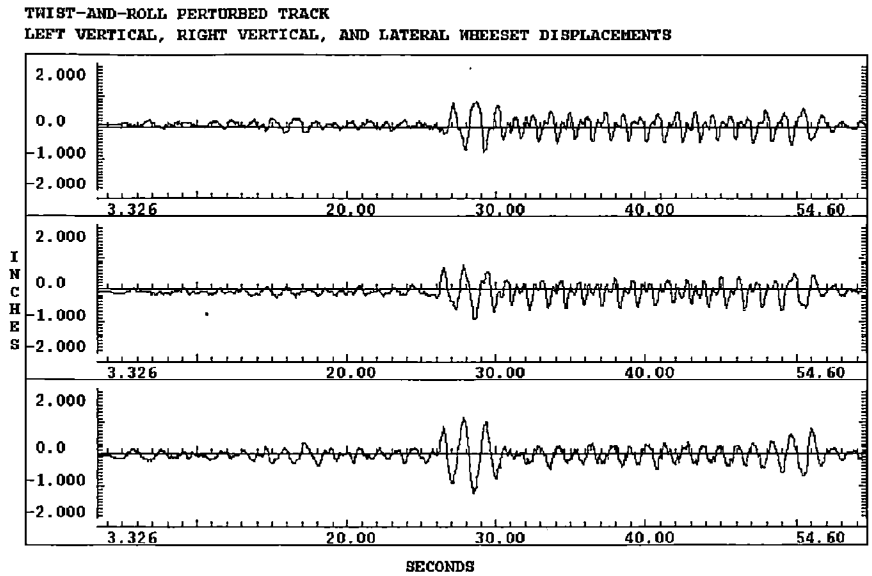

Figure 7. Time Histories of Left and Right Wheel Vertical Displacements, Lateral Axle Displacement Obtained from Testing on Twist-and-roll Track

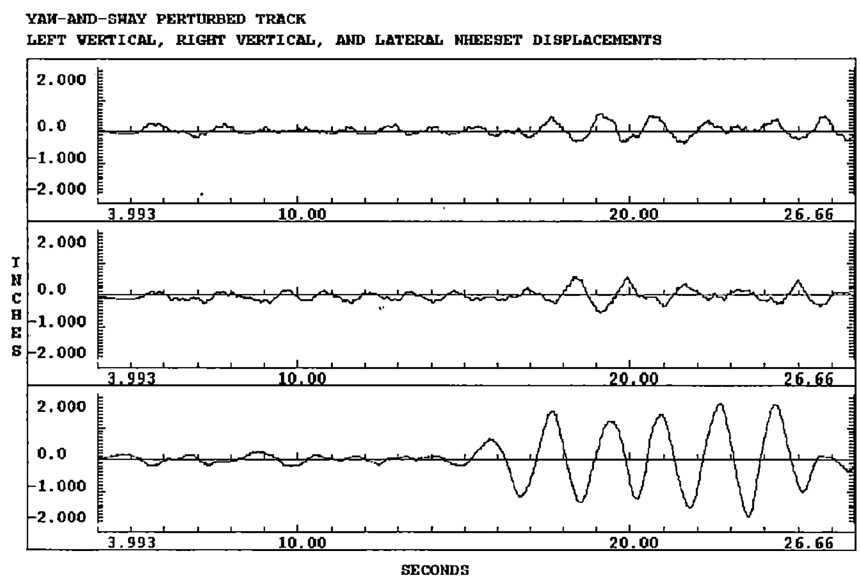

Figure 8. Time Histories of Left and Right Wheel Vertical Displacements, Lateral Axle Displacement Obtained from Testing on Yaw-and-sway Track

5.3.2 Inputs for Simuloader Tests on Car without Suspension

Piezo-resistive type accelerometer measurements AR1Z, AL2Z, AR3X, AR4Z, AL5Z, and AR6X were used to record car body vertical and lateral accelerations for subsequent use as inputs for testing with the car body mounted directly onto the Simuloader. During the Simuloader testing, however, it was found that the electronic integraters supplied with the Simuloader control system did not adequately convert the accelerations into Simuloader displacement drive signals. For this reason, an alternative was used to record and develop inputs for the Simuloader testing without the railcar's suspension. To avoid additional costs, due to repeating the on-track testing, this method was implemented during Simuloader tests on the car with the car's suspension.

6.0 SIMULOADER TESTS

6.1 SIMULOADER TEST FACILITY

The Simuloader is a system of hydraulic actuators, power sources, electronics, and computers that work together to reproduce vertical, lateral, and yaw displacements. These are usually input into the test car at the truck bolster to car body interface. The Simuloader also can introduce longitudinal loads through the railcar's couplers. The fatigue machine, manufactured by MTS Corporation, can excite the test car with profiles and waveforms that represent the bolster's response to actual railroad environment. The Simuloader is designed to run efficiently for long periods of time, which makes it particularly well suited for fatigue tests.

The Simuloader is located in the Rail Dynamics Laboratory (RDL), a 55,000 square foot, high-bay building, which also houses other test facilities including the VTU, the Roll Dynamics Unit, the Traction Motor Test Stand, the Mini-Shaker Unit, and the Container/Package Laboratory.

Instrumentation, data collection and analysis equipment, and vehicle handling equipment also are located in the RDL. The systems in the RDL can duplicate, in a controlled environment, the forces and stresses that affect rail vehicles, or other vehicles and structures. This can be done while taking measurements of response phenomena. The RDL is served by two rail tracks. Two 100-ton capacity traveling bridge cranes are used to position equipment for testing.

In its original configuration, the Simuloader includes four vertical 110-kip, two lateral 77-kip, and four yaw 22-kip electrohydraulic actuators that are displacement controlled, and one longitudinal actuator that is force controlled. The lateral, vertical, and yaw actuators induce motion into a truck bolster-like interface. The longitudinal actuator, which is controlled with a load measuring coupler, is capable of applying 750-kip buff and 600-kip draft. The yaw actuators are used mainly to support the assembly. The vertical and lateral actuators were used for this test program. The longitudinal coupler force and bolster yaw actuators were not utilized.

The actuators use MTS 256 and 252 servo-valves. The actuators' hydraulic supply requirement is met by six 55 gallon-per-minute pumps, for a total capacity of 330 gallons per minute. The operating pressure is 3,000 psi.

The Simuloader was modified to accept the single-axle test car with and without the car's suspension. Figure 9 shows the test car installed with its suspension on the Simuloader.

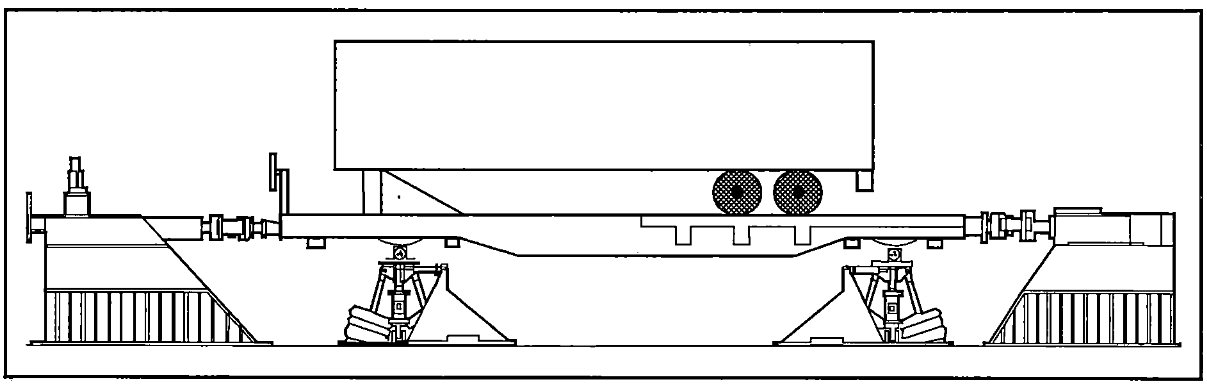

Figure 9. Test Car with Suspension on Simuloader

6.2 INSTRUMENTATION

The instrumentation used during the on-track testing was duplicated during the Simuloader tests. For the Simuloader tests on the intermodal test car with its suspension, additional car body to ground displacement measurements were recorded. These measurements were added as an alternate means to develop Simuloader excitation inputs for testing without the car's suspension.

6.3 TESTING

6.3.1 Simuloader Tests on Car with Suspension

Simuloader tests on the car with its suspension were done to determine the effectiveness of the Simuloader to reproduce Class 2 track, Class 5 track, twist-and-roll perturbed track, and yaw-and-sway perturbed track, and to obtain data for the conduct of Simuloader tests on the car without the car's suspension. In addition, rigid-body modal Simuloader tests were performed on the car with its suspension to allow the similarities between the Simuloader and the VTU to be evaluated. Thirty-five runs were conducted to accomplish the above.

6.3.2 Simuloader Tests on Car without Suspension

Tests were done on the car without its suspension to show the Simuloader's capability to replicate vibrations caused by Class 2 track, Class 5 track, twist-and-roll perturbed track, and yaw-and-sway perturbed track into unsuspended test vehicles. It was correctly anticipated that testing on unsuspended vehicles would allow more efficient fatigue testing techniques to be utilized -- including accelerated-rate fatigue testing developed under subsequent test programs.

Initially, it was planned to use built-in hardware on the Simuloader control system to double integrate car body accelerations to provide the displacements necessary to excite the Simuloader's vertical and lateral actuators. However, checkout of the integraters during testing with the test car's suspension showed that the integraters did not provide adequate displacement signals. Thus, car-body-to-ground displacement measurements, added during the later stages of the Simuloader testing on the car with its suspension, were utilized.

The initial testing allowed the inputs to be developed and validated. The testing was concluded by repeating the Class 2 track input to correspond to 300 miles of Class 2 track.

6.3.3 Test Log

Table 1 summarizes the test log of the railcar with and without its suspension.

Table 1. Simuloader Test Run Log Summary

Date	Test
6/27/86 to 7/3/86	Simuloader testing railcar with its suspension -- Class 2, Class 5, twist-and-roll, and yaw-and-sway track simulations.
7/17/86 to 9/11/86	Simuloader testing railcar without its suspension -- Class 2, Class 5, twist-and-roll, yaw-and-sway track simulations, and 300 miles of repeated Class 2 simulations.

6.3.4 Car Inspections

Car inspections were performed periodically by members of the TTC Rail Vehicle Maintenance Department. The inspections were used to assess the car's structural integrity and to record fatigue damage. Testing resulted in no damage to the test vehicle -- the result of the low-mileage simulated (300 miles).

6.4 SIMULOADER TEST DATA ANALYSIS AND RESULTS

6.4.1 Results on Car with Suspension to Compare Simuloader and VTU

To compare the Simuloader to the VTU, rigid-body modal tests were performed. These tests consisted of 0.5-5 Hz sinusoidal waveforms input in various phase relationships into each of the VTU and Simuloader vertically oriented actuators.

Table 2 lists example resonant frequencies from VTU and Simuloader rigid-body bounce modal testing. The VTU tabulated test data was obtained from FRA report No. FRA/ORD-88/07, *Safety Aspects of New and Untried Freight Cars.* Figure 10 displays the PSD used to obtain the result for the Simuloader testing.

Table 2. Comparison of Simuloader and VTU Sinewave Test Results

Test	Simuloader	VTU
Natural frequency due to 1-5 Hz sine sweep with vertical actuators in phase	1.875	1.8 Hz

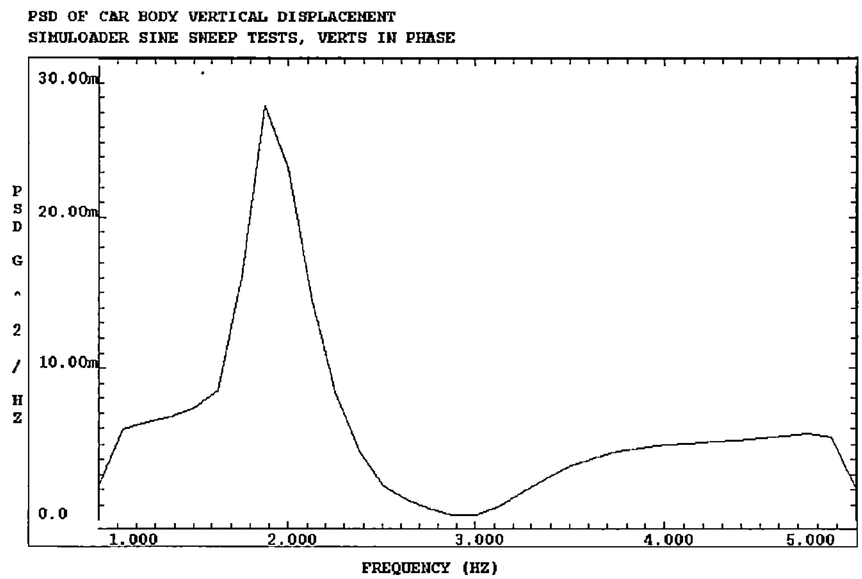

Figure 10. PSD of Car Body Vertical Displacement, Simuloader Sine Sweep Test with Vertical Actuators In Phase

6.4.1.1 Discussion of Results on Car with Suspension

The bounce test results given in Table 2 showed strong correlation between the Simuloader and VTU test systems -- thus demonstrating that the Simuloader performs very much like the VTU when excited by mathematical profiles.

6.4.2 Results on Car with and without Suspension Compared to On-track Data

Usually, a fatigue-test input development procedure requires rainflow counting and subsequent fatigue life estimation to "fine-tune" the drive file. This assures matching of the computed fatigue life based upon on-track test stress cycles. For this test, however, significant strains were not encountered at the locations instrumented with strain gages for the on-track and Simuloader tests. Therefore, time histories and PSD's were used as the tool for comparison of on-track test results to Simuloader test results, and the 300 miles of test data was not used to evaluate fatigue performance.

Table 3 lists the comparisons made for on-track testing: Simuloader testing with the car's suspension, and Simuloader testing without the car's suspension.

Table 3. Matrix of Tests Used for Comparison of On-track and Simuloader Test Results

Test	On-track Testing	Simuloader w/suspension	Simuloader w/o Suspension
PDA Class 2 track at 15 mph	X	X	data not recoverable
Twist-and-roll perturbed track	X	X	X
Yaw-and-sway perturbed track	X	X	X

Figure 11 displays PSD's of lateral car body acceleration responses on Class 2 track respectively, comparing Simuloader testing on the car with its suspension to Simuloader testing on the car without its suspension. Data from the Class 2 on-track testing was not recoverable. PSD's are utilized due to the random nature of the Class 2 track.

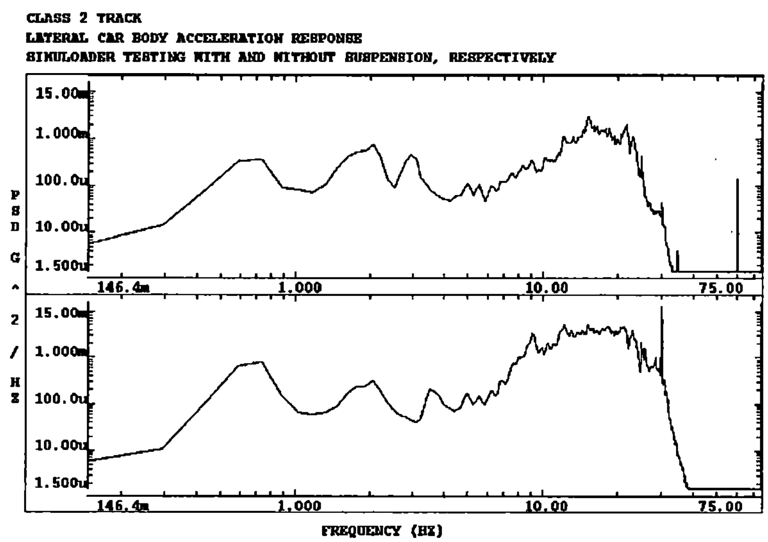

Figure 11. PSD's of Car Body Lateral Accelerations on Class 2 Track, Measurement AR3X -- Simuloader Testing with and without Suspension

Figure 12 shows trailer roll time histories for twist-and-roll performance on-track and on the Simuloader, with and without the test vehicle's suspension. Similarly, Figure 13 depicts car body roll time histories for yaw-and-sway performance.

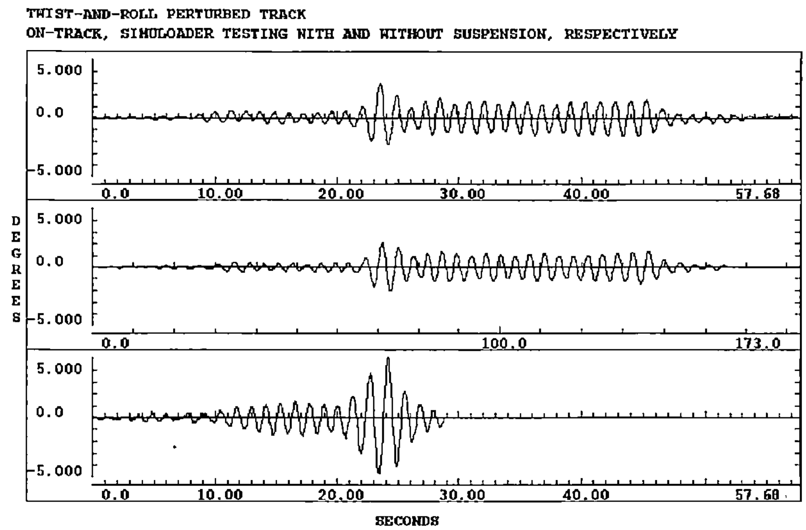

Figure 12. Time Histories of Trailer Roll on Twist-and-Roll Perturbed Track -- On-track Testing, Simuloader Testing with Suspension, Simuloader Testing without Suspension

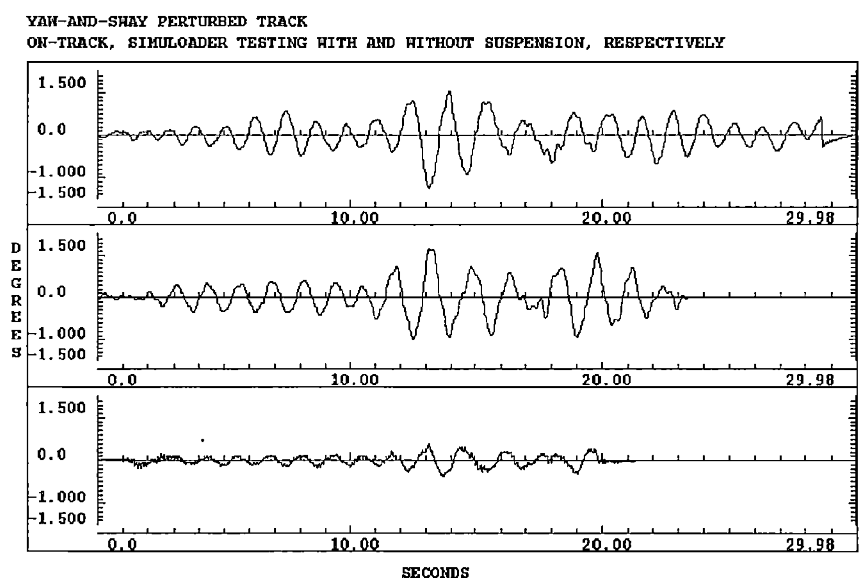

Figure 13. Time Histories of Trailer Roll on Yaw-and-sway Perturbed Track -- On-track Testing, Simuloader Testing with Suspension, Simuloader Testing without Suspension

6.4.3 Discussion of Results on Car with and without Suspension Compared to On-track Data

Figure 11 demonstrated the Simuloader's capability to re-create random Class 2 track car body responses with and without the test car's suspension, as indicated by the similarity of the distribution of energy at each frequency. The Simuloader data without suspension was found to be of greater magnitude, however.

Figures 12 and 13 allowed comparisons of time histories from on-track testing, and Simuloader testing with and without suspension. The Simuloader testing with suspension showed results which were similar, but less in magnitude. In contrast, the Simuloader testing without suspension produced results which were significantly greater in magnitude, causing the test runs to be stopped prematurely for safety considerations. With further testing, these variances can be corrected, as has been shown in subsequent FRA, AAR, and commercially sponsored test programs. The primary reason for the improvement during subsequent programs was the adaptation of the LTHD system to obtain inputs for testing unsuspended railcar bodies, and the use of fatigue evaluation methods to adjust the input levels.

7.0 CONCLUSIONS

Conclusions can be drawn from the following course of testing.

- Techniques developed previously for obtaining inputs for the VTU can be used to generate inputs for the Simuloader.
- The Simuloader was able to invoke car body responses similar to responses when testing on the VTU.
- The Simuloader was found to excite test car responses with and without suspension in a manner similar to responses encountered on-track. With practice and experimentation, differences in response amplitudes can, and have in subsequent test programs, be reduced to acceptable, minimal levels.