

# Investigation of Feasible Methods for Implementing Performance-based Track Geometry Standards

by  
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## Summary

A series of in-service tests and analytical studies were conducted to investigate the effects of track geometry defects on vehicle performance and to explore feasible methods for implementing performance-based track geometry standards. The results indicate that the vehicles primary vertical response depends on the length and depth of the defect, the type and number of defects, and the operating speed. The results also indicate that track geometry car data can eventually be directly used to predict vehicle performance. This linkage would be necessary in order to implement a vehicle performance based track geometry standard.

Several geometry and vehicle defects were detected during tests over 740 miles of track on one railroad. At eleven locations, car bolster lateral loads exceeded the threshold level. Although most of these exceedences were due to turnouts, a lateral alignment variation on a bridge and on a curve resulted in lateral bolster loads that exceeded the threshold level. Also, several FRA or railroad defects such as dips, surface, warp, alignment, and cross level defects were detected. The vehicle response from dip defects are reported here. Vehicle response to other defects will be reported in a future digest. The tests showed that multiple dips in the track can produce the highest loads in the vehicle. Vehicle response depends on the length and depth of the defect as well as the speed. Also, analytical studies (NUCARS) performed with the paint-spotter car showed that the vehicle response over a given track can be reasonably predicted when provided with track geometry data from a geometry car.

The AAR has instrumented a 70-ton "paint-spotter" box car to measure and identify track surface anomalies that produce high lateral and vertical loads. This car was operated in conjunction with track geometry cars from three railroads over 1700 miles of track. Both track geometry and vehicle performance data were collected. Tests were also conducted at the Transportation Technology Center to identify the vehicle's suspension parameters. From this data, a NUCARS model was developed to investigate the performance of the vehicle over tracks with anomalies.



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### **Suggested Distribution:**

- Operating/Engineering Department
- Maintenance of Way/Planning
- Track Maintenance
- Research and Development



## INTRODUCTION AND CONCLUSIONS

The dynamic interaction between freight car and track is an important area of study in railroad research, since it may result in damage to the track, freight car, and/or its contents. The need to control this dynamic interaction is not a new endeavor, but it has been emphasized with the increase in train speed and axle loads.

As part of the Vehicle Track Systems (VTS) program, AAR staff performed tests to quantify the effect of track irregularities on railway vehicles. A series of in-service tests using the AAR-101, paint-spotter car, showed that vertical track irregularities can cause vertical bolster loads in excess of 3 to 4 times the static load level [AAR Report R-694]. In another series of tests to measure the effects of lateral track irregularities on vehicle response, the paint-spotter car identified two types of lateral track irregularities (TD93-004). The first type was characterized by discrete irregularities such as a switch, or a frog point on a turnout. The second type were multiple track irregularities that excited one of the vehicle's rigid body resonance modes. At most of the locations identified by the paint-spotter car, the track geometry car did not indicate a problem. AAR research concluded that most track geometry cars in service are configured to detect single FRA-type track geometry defects. No consideration is given to the implications of a series of defects that can cause severe vehicle response and possibly lead to derailment.

In order to investigate the relationship between FRA track geometry defects (track geometry exceptions recorded by the track geometry car) and the vehicle response, the paint-spotter car was used in conjunction with railroad geometry cars. The leading truck of the AAR paint-spotter car was instrumented to measure lateral and vertical loads and accelerations. It was then run over 1700 miles of track on three railroads. An analytical model of the car was developed for use with AAR's New and Untried Car Analytic Regime Simulation (NUCARS) program. The model was calibrated with data from laboratory tests and then validated with actual data from the road tests. Due to the massive amount of data collected, this digest discusses only vertical track geometry and vertical vehicle response from dip defects. The results from lateral defects will be the subject of future technology digests.

Based on the road tests and analytical model results, the following conclusions were reached:

- Dip defects induced the highest bolster loads in the test car. These loads ranged from 110,000 to 330,000 pounds for speeds ranging from 18 to 60 mph and dips of 0.6 to 1.4 inches. The static bolster load for this car was 100,000 pounds.
- Load magnitude depends on vehicle speed, as well as the depth and length of the defect.
- Multiple defects produced higher bolster loads than a single defect.
- NUCARS can be used to effectively model the paint-spotter car. A vertical model of the car was validated with mini-shaker results and road tests.
- There was a strong correlation between the measured values and the model's prediction of bolster load and spring displacement.
- The paint-spotter car model can be used to study the effect of FRA-type track geometry defects or any other defects and speed combination on vertical car response.

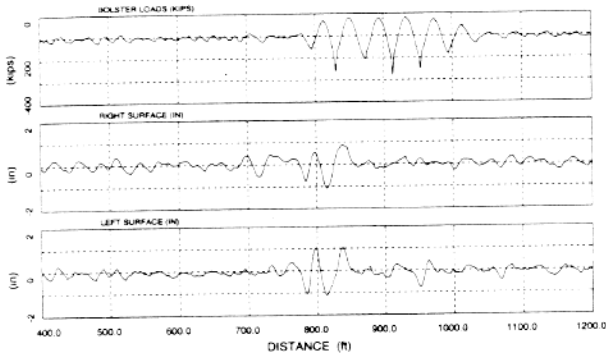
## PAINT-SPOTTER CAR TEST

The paint-spotter car is a standard 70-ton box car with a truck center spacing of 41 feet. It is equipped with conventional three-piece, Barber S2 trucks that have variable column damping with roller side bearings. The paint-spotter car is instrumented to measure the vertical and lateral bolster loads, secondary suspension displacement, and lateral bolster acceleration on the leading truck. In addition, car body lateral and vertical accelerations are measured at both ends of the car. The paint-spotter car data collection system was modified to accept the track geometry data collected by the geometry car.

In summer and fall of 1993, this vehicle and the track geometry car from each of three railroad companies were run over 1700 miles of track. Data from these tests were used to investigate the effects of track geometry on vehicle performance and to investigate feasible methods of implementing performance-based track geometry standards. The vehicle and track geometry data was collected at locations where the FRA track safety standards were exceeded or vehicle lateral/vertical bolster loads exceeded 30,000 pound/180,000 pound thresholds. Data from one of the railroads tested showed 82 dip defects, 119 surface defects, 39 warp defects, 11 alignment defects, and 21 cross level defects. The lateral bolster load exceeded

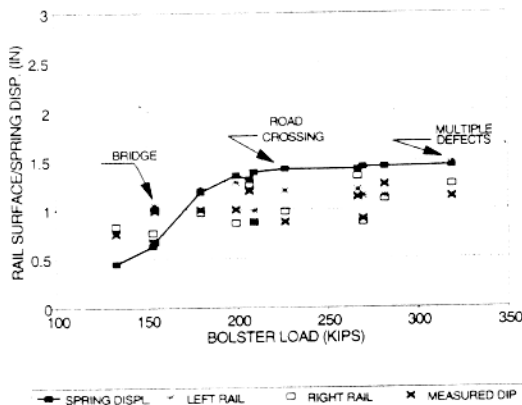


the threshold 9 times. The majority were due to switches, although 2 exceedances were due to alignment on a curve and on a bridge. This digest discusses only dip defects in open track with both vehicle and geometry data. Dips ranged from 0.6 to 1.4 inches and bolster loads were between 110,000 and 330,000 pounds (the static bolster load is 100,000 lbs)



**Exhibit 1. Track Surface, Bolster Loads, 60 mph, Multiple Defects.**

at speeds from 18 to 60 mph. The results showed that most of the high bolster loads were produced at the high speed range. Exhibit 1 shows a plot of the track surfaces and vertical bolster loads for one of the locations with multiple defects. Exhibit 2 shows spring displacements and rail surface dip vs. bolster loads at 60 mph.



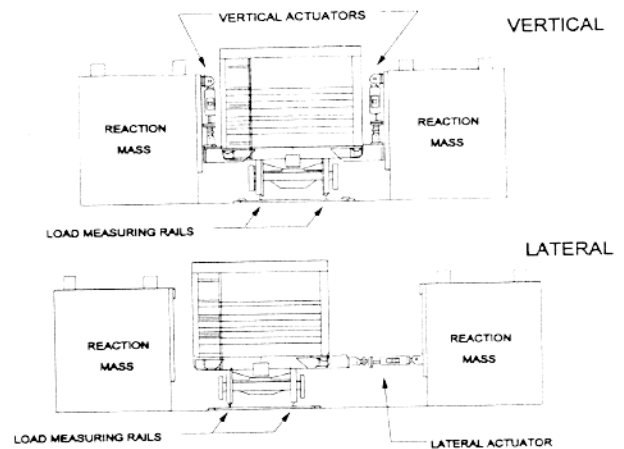
**Exhibit 2. Bolster Loads Versus Rail Surface and Spring Displacements at 60 mph for Dip Defects.**

This exhibit also shows vehicle response at a bridge approach, road crossing, and open track with multiple defects. It can be seen that multiple defects produced the highest bolster loads (330,000 pounds). The loads on the bridge approach with the same dip were

approximately 180,000 pounds. This indicates that even though the speed and depth of the defects are the same at both locations, multiple defects induced more severe response in the vehicle. The examination of other defects as well as any relationship between FRA defects and vehicle response will be reported in future digests.

**ANALYTICAL MODELING OF THE PAINT-SPOTTER CAR**

NUCARS was used to predict the paint-spotter car's response to the track irregularities. NUCARS is an analytic multi-body system simulation program which models a rail vehicle's transient and steady state response. To determine the suspension inputs for NUCARS, the paint-spotter car was taken to the Transportation Technology Center in Pueblo, Colorado and tested using the mini-shaker unit (MSU). To measure the suspension characteristics of each truck, the car was installed in the MSU (Exhibit 3) and excited by actuator(s) in the vertical and lateral directions at frequencies from 0.3 to 3.0 Hz. This range was chosen to cover all frequencies for vertical and lateral responses. In each vertical and lateral case, the suspension displacements and forces were measured.

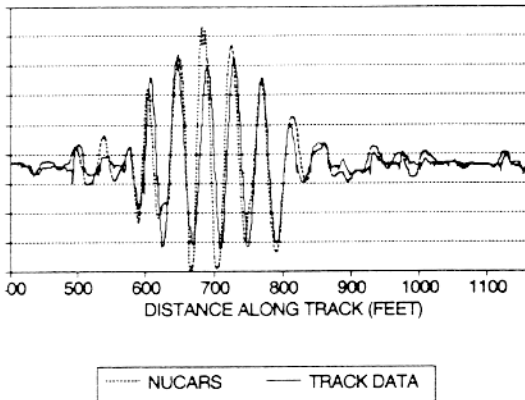


**Exhibit 3. Mini-Shaker Unit (MSU).**

The damping and stiffness levels were established through the force-deflection hysteresis curves. The initial assembly of the model consisted of linking together the physical bodies which are influential in the response of the rail car.



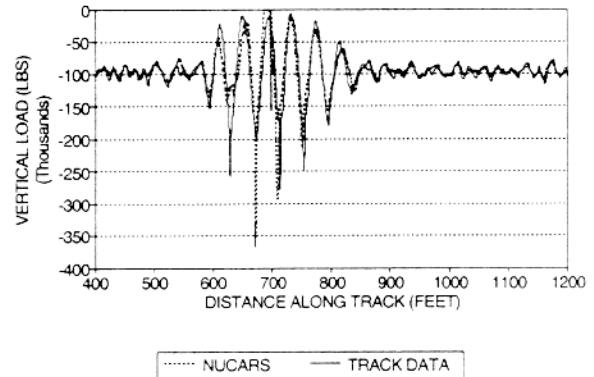
### LEFT SPRING TRAVEL NUCARS VERSUS REVENUE TRACK DATA



**Exhibit 4. NUCARS Predicted Versus Measured Spring Travel.**

These links are actually connection elements of various types. The hysteresis type connections were included to represent the force deflection hysteresis measured from MSU tests. The validity of the model was determined by comparing data collected on revenue service track to NUCARS' predicted response of the paint-spotter car. Vertical track profile data collected on a track geometry car was used as input to NUCARS. The left and right rail vertical profiles are given in Exhibit 1. In looking at the figure, notice that there are two consecutive dips in the profile around the 850 foot marker. The NUCARS simulation was run at the same speed as the actual test car.

### VERTICAL BOLSTER LOAD NUCARS VERSUS REVENUE TRACK DATA



**Exhibit 5. NUCARS Predicted Versus Measured Vertical Bolster Loads.**

Plots of NUCARS' predicted spring travel versus the measured spring travel are shown in Exhibit 4. The correlation is shown in the region stimulated by the dip as well as in the flatter region. Both the frequency and amplitude of oscillation are roughly the same throughout the entire track section. The vertical bolster load comparison is given in Exhibit 5. The validity of the model is demonstrated in its ability to predict both high and low frequency response. Again the correlation is strong throughout in both amplitude and frequency.

*Note: Contact Ali Tajaddini at (312) 808-5850 with questions or comments about this document.*

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