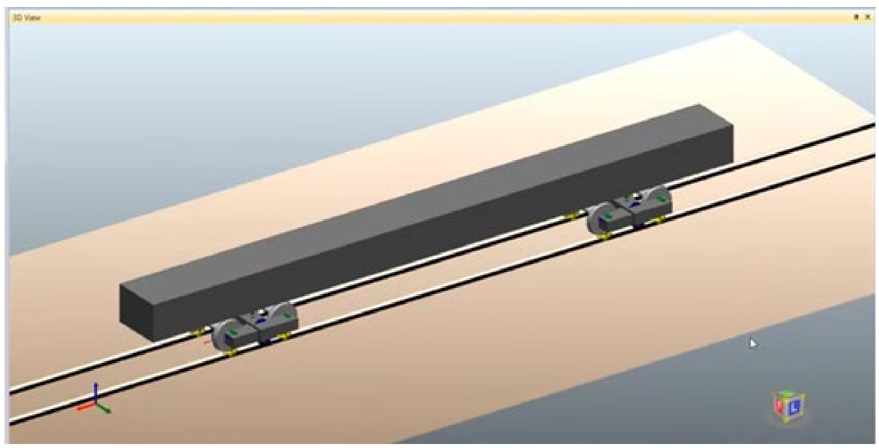
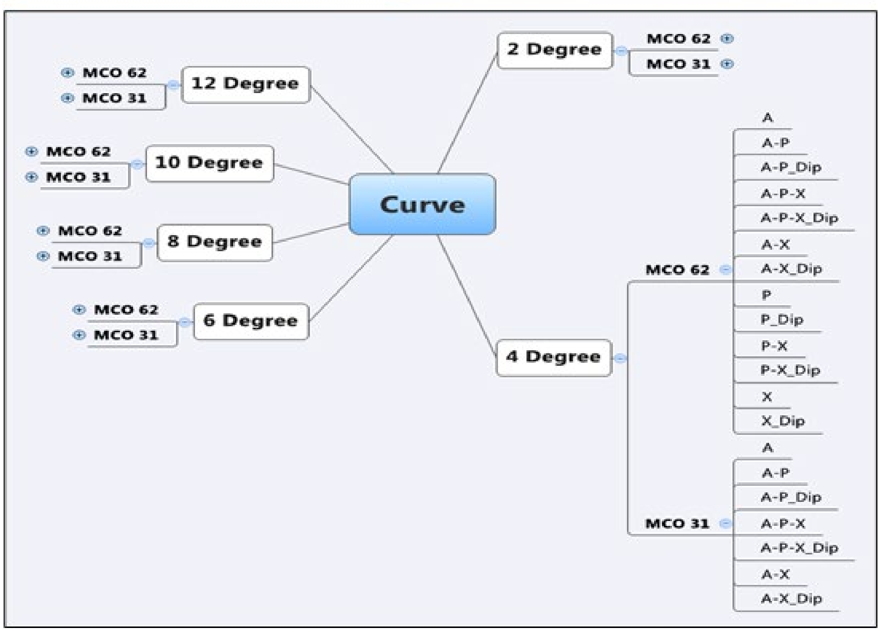
U.S. Department of Transportation

Federal Railroad Administration

Office of Research, Development and Technology
Washington, DC 20590

Track Geometry and Vehicle Performance Parametric Study Using NUCARS®





DOT/FRA/ORD-26/08 Final Report | July 2026

REPORT DOCUMENTATION PAGE					*Form Approved* *OMB No. 0704-0188*

1. REPORT DATE *(DD-MM-YYYY)*	**2. REPORT TYPE**	**3. DATES COVERED** *(From - To)*
29 July 2026	Technical Report	Sept. 1, 2013 to Oct. 31, 2014

4. TITLE AND SUBTITLE	**5a. CONTRACT NUMBER** **DTFR53-11-D-00008**
Track Geometry and Vehicle Performance Parametric Study Using NUCARS®	**5b. GRANT NUMBER**
	5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S) **Abe Meddah: ORCiD #0000-0002-0268-1327** **Curtis Urban**	**5d. PROJECT NUMBER**
	5e. TASK NUMBER **Task Order 344**
	5f. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)	**8. PERFORMING ORGANIZATION REPORT NUMBER**
Transportation Technology Center, Inc. 55500 DOT Road Pueblo, CO 81001-0130	
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	**10. SPONSOR/MONITOR'S ACRONYM(S)**
U.S. Department of Transportation Federal Railroad Administration 1200 New Jersey Avenue, SE Washington, DC 20590	**11. SPONSOR/MONITOR'S REPORT NUMBER(S)** DOT/FRA/ORD-26/08

12. DISTRIBUTION/AVAILABILITY STATEMENT
This document is available to the public through the FRA website.

13. SUPPLEMENTARY NOTES
COR: Abe Meddah

14. ABSTRACT

The Federal Railroad Administration (FRA) sponsored an all-inclusive parametric study using NUCARS® to assess vehicle performance of five vehicle types over analytically-defined track perturbations. The research team performed the vehicle performance assessment using criteria from both the Association of American Railroads' Chapter 11 and FRA Title 49 Transportation Code of Federal Regulations Part 213 Track Safety Standards. In the simulation work, a matrix of the maximum allowable limits for track alignment, surface and cross-level deviations over Track Classes 1 through 5 was used. The simulation matrix included single track deviations as well as synchronized combined track deviations.

15. SUBJECT TERMS
NUCARS®, vehicle dynamics, wheel/rail interaction, track geometry

16. SECURITY CLASSIFICATION OF:			**17. LIMITATION OF ABSTRACT**	**18. NUMBER OF PAGES**	**19a. NAME OF RESPONSIBLE PERSON**
a. REPORT **Unclassified**	**b. ABSTRACT** **Unclassified**	**c. THIS PAGE** **Unclassified**		117	**19b. TELEPHONE NUMBER** *(Include area code)*

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Executive Summary

The Federal Railroad Administration (FRA) tasked Transportation Technology Center, Inc. (TTCI), now MxV Rail, to conduct a parametric study using NUCARS®[1]. The study assessed the performance of five vehicle types over analytically defined track perturbations. The project team assessed vehicle performance using criteria from both the Association of American Railroads' (AAR) "Service-worthiness tests and analyses for new freight cars" [1] and 49 CFR Part 213 Track Safety Standards Subpart C Track Geometry [2]. This report describes the simulation work performed and the results obtained.

Vehicle type selection for the simulation work was based on the number of accidents per million miles that various vehicles experienced. NUCARS models were developed for the following car types:

- Empty and loaded tank cars
- Empty and loaded flat cars
- Loaded hopper car (base car)

In the simulation work, the team used a matrix of the maximum allowable limits for track alignment, surface, and cross-level deviations over track Classes 1 through 5. The simulation matrix included single track deviations and synchronized, combined track deviations. The team designed and simulated track deviations using sine-wave input shapes starting at the maximum allowable limits for each Class of track. The simulation matrix was run for every vehicle type.

The research team investigated a wide range of curvatures and mid-chord offsets (MCO). Curvature varied from tangent to 12 degrees in 2-degree increments, and MCOs were simulated for 31-foot and 62-foot chord lengths. For curved tracks, coefficients of friction representing dry and lubricated track conditions were used and set to 0.5 and 0.2, respectively. All track geometry deviations were simulated as in-phase track deviations, present at the same locations.

To determine the relative effect of each track geometry variable in the "derailment/extreme exceedance" cases (as determined from NUCARS simulations), the research team established a pass/fail/derail criterion and reduced track alignment, surface, and cross-level from their maximum values by 0.1-inch steps. They ran simulations until the vehicle would no longer experience adverse dynamic responses.

Tangent Track Simulations

No derailment/extreme exceedances were recorded in simulations on tangent track by any vehicle. Simulation regimes that did not exceed performance preset criteria (AAR Chapter 11 and CFR 213 standards) far outnumber the ones that exceeded. Both standards also show that empty tank and empty flat cars generated more exceedances than the other vehicle types. For a close comparison between CFR 213 and AAR Chapter 11 standards, L/V ratio criterion was used. A few exceedance cases, per AAR standards, were generated by both empty tank and empty flat cars. Per CFR 213 standards, none of the vehicle types generated exceedance.

[1] NUCARS® is a registered trademark of Transportation Technology Center, Inc., Pueblo, Colorado

Curved Track Simulations

The five vehicle types displayed different dynamic performances over the same curves, same track deviations, and same operating speeds (i.e., maximum track speeds). The empty tank and empty flat cars presented the highest exceedance instances based on both AAR Chapter 11 and CFR 213 criteria. Those two cars also generated the highest numbers of extreme exceedances/derailment cases. The loaded hopper car (the base comparison car) displayed the least adverse dynamic behavior. The research team ran all the simulation regimes run on dry curves again in lubricated conditions, with coefficient of friction set to 0.2. Lubricating the curved track eliminated all the derailment cases and significantly reduced exceedance instances.

Empty Tank Car

Thirty-one cases had extreme exceedances/derailments. Nearly half of them occurred in Class 1 track deviations. Track alignment, surface, and cross-level were, in turn, reduced from their maximum values by 0.1-inch steps to resolve those cases. All derailments were resolved except three "down and out" Class 1 track regimes. The phrase down and out refers to a vertical dip in the high rail and an outward lateral displacement of track alignment. The phrase "up and out" is the reverse situation, in which the high rail is displaced vertically upward as the alignment is pushed outward. Alignment deviation was reduced to 0 inch while maintaining profile and cross-level at maximum limits, yet the car still derailed. However, reducing surface and cross-level while maintaining alignment deviation at its maximum limit eliminated the extreme derailment and exceedance cases. This solution may indicate that track alignment deviations are less dominant in causing adverse dynamic behavior.

Loaded Tank Car

There were 14 cases with derailment instances; all occurred in Class 1 track regimes. Like the empty tank car, six up and out regimes were not resolved. In each of these regimes, track alignment was reduced to 0 inch while maintaining the profile and cross-level at their maximum limits, yet the loaded tank car still derailed. Nonetheless, these derailment cases were resolved by reducing profile and cross-level while maintaining track alignment at its maximum allowable limit. This solution may indicate that track alignment deviations are less dominant in causing adverse dynamic behavior.

Empty Flat Car

The empty flat car experienced 17 derailments. There were two down and out Class 1 track regimes for which derailments kept occurring, even while reducing the track alignment to 0 inch and profile and cross-level were set to their maximum allowable limits. However, these two derailment regimes improved after reducing profile and cross-level and maintaining alignment at its maximum limit. Again, this may denote that track alignment deviations are less dominating in causing adverse dynamic behavior.

Loaded Flat Car

The loaded flat car experienced two derailment cases, one on Class 3 track and one on Class 4 track. The Class 3 track was a down and out regime and the other was a Class 4 track up and out. Geometry variables were reduced from their maximum values by 0.1-inch steps, which helped resolve these derailment cases.

Loaded Hopper Car

The loaded hopper car had one derailment instance. This occurred in a Class 1 track down and out regime. Geometry variables were reduced from their maximum values by 0.1-inch steps, which helped resolve this derailment case.

1. Introduction

The Federal Railroad Administration (FRA) tasked Transportation Technology Center, Inc. (TTCI), now MxV Rail, to conduct a parametric study using NUCARS®[2]. The study assessed the performance of five vehicle types over analytically defined track perturbations. The project team assessed vehicle performance using criteria from both the Association of American Railroads' (AAR) "Service-worthiness tests and analyses for new freight cars" [1] and 49 CFR Part 213 Track Safety Standards Subpart C Track Geometry [2]. This report describes the simulation work performed and the results obtained.

Measurement of track geometry is part of the conventional inspection method to ensure that track meets safe operational standards. Such an inspection compares measured values of several track geometry parameters with pre-set limits to determine if the safety or maintenance limits are exceeded. FRA track geometry limits serve to identify conditions that require immediate attention because they pose a potential safety hazard.

1.1 Background

Typical measured track geometry parameters are:

- Gage
- Curvature
- Superelevation
- Left and right rail alignment
- Left and right rail surface (profile)

From these measured parameters, limits are set for maximum allowable amplitudes or deviations for track Classes 1 through 9 and resulting speed limits. Although FRA has prescribed limits on single track geometry variations, combinations of allowable alignment, surface, and cross-level variations, none of which individually amount to a defect, may result in undesirable vehicle response. Figure 1 illustrates a revenue service example of track geometry conditions that produced adverse vehicle responses (lateral to vertical wheel load ratio, L/V greater than 1.0). As shown, none of the individual track geometry parameters had deviations exceeding FRA track geometry standards (indicated by the blue arrows), but the combined track geometry deviations led to two vehicle response exceptions over this track segment. Current track geometry standards would not have identified that track location as an exception location.

[2] NUCARS® is a registered trademark of Transportation Technology Center, Inc., Pueblo, Colorado

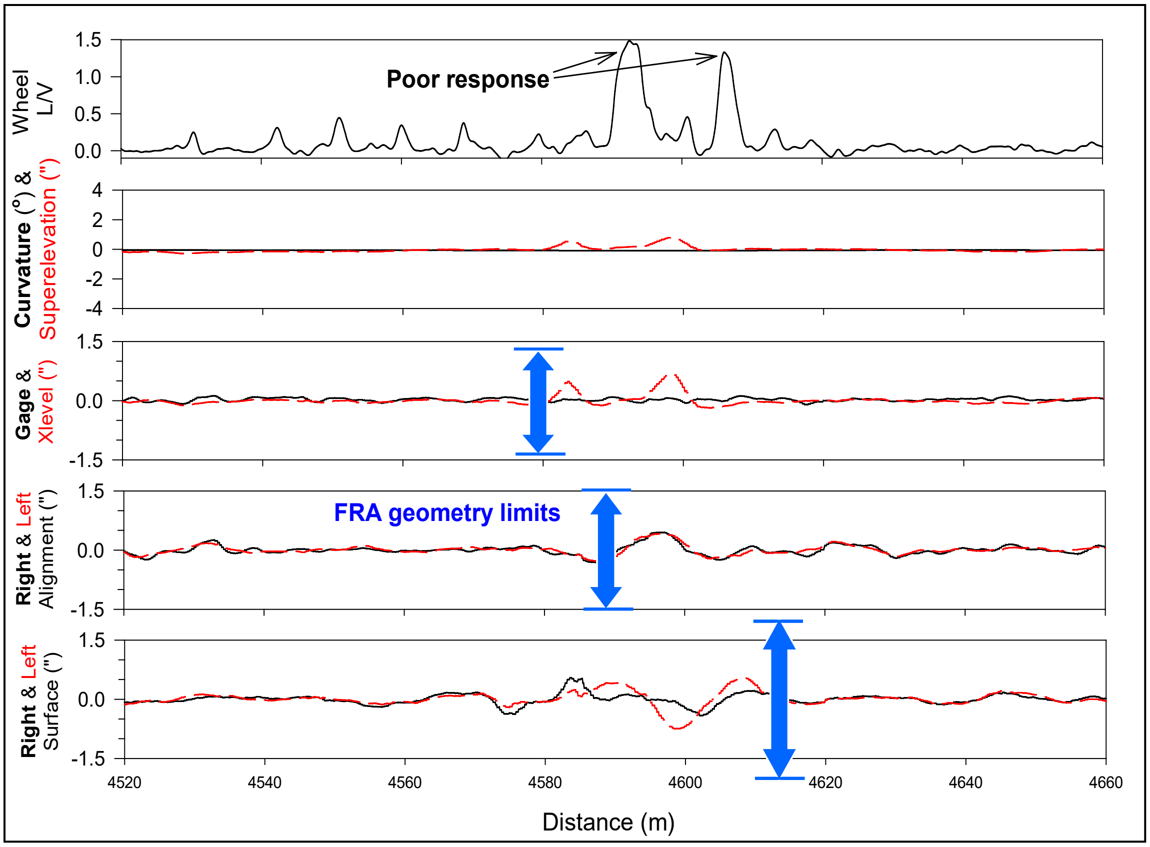

Figure 1. Poor Vehicle Responses Recorded at 43 mph on Tangent Due to a Combination of Cross-Level, Alignment and Surface Deviations

1.2 Objectives

The main focus of the parametric study work was to investigate the dynamic performance of five freight railcars using maximum allowable track geometry in-phase deviations for track Classes 1 through 5 using the multi-body dynamic simulation software model NUCARS. The research team limited the simulation work to investigating the effects of track alignment, surface, and cross-level deviations present at the same locations. Operating speeds did not vary during the simulations and aligned to maximum allowable limits for each Class of track.

The selected five railcars were as follows:

- Empty and loaded tank cars
- Empty and loaded flat cars and
- Loaded hopper/gondola car (base car)

The tank and flat car types were selected based on the number of derailments per million miles.

1.3 Overall Approach

The team used an approach that simulated the dynamic behavior of selected vehicle types using a matrix of the maximum allowable limits for track alignment, surface, and cross-level deviations over track Classes 1 through 5. Table 1 shows the simulation matrix for track geometry parameters, single deviations and combined. The team designed analytically defined track deviations and simulated them using sine-wave inputs starting at the maximum allowable limits for each Class of Track, as established in Track Safety Standards CFR Part 213 (Table 2 and Table 3). Figure 2 shows a Class 3 example of designed track geometry deviations that were used in the simulations. Deviations of track in phase alignment, profile, and cross-level are illustrated.

Table 1. Simulation Matrix

	Alignment (A)	**Surface/Profile (P)**	**Cross-Level (X)**	**Combined**
Alignment (A)	A only			
Surface/Profile (P)	A-P Combination	P only		
Cross-Level (X)	A-X Combination	P-X Combination	X only	
Combined				A-P-X Combination

Table 2. Track Geometry Standards 213.55 for Track Alignment

Class of Track	**Tangent Track**	**Curved Track**	
	The deviation of the mid-offset from a 62-foot line[1] may not be more than (inches)	The deviation of the mid-ordinate from a 31-foot chord[2] may not be more than (inches)	The deviation of the mid-offset from a 62-foot chord[2] may not be more than (inches)
Class 1 Track	5	N/A[3]	5
Class 2 Track	3	N/A[3]	3
Class 3 Track	1 ¾	1 ¼	1 ¾
Class 4 Track	1 ½	1	1 ½
Class 5 Track	¾	½	5/8

[1]The ends of the line shall be at points on the gage side of the line rail, five-eighths of an inch below the top of the railhead. Either rail may be used as the line rail; however, the same rail shall be used for the full length of that tangential segment of track.
[2]The ends of the chord shall be at points on the gage side of the outer rail, five-eights of an inch below the top of the railhead.
[3]N/A = not applicable

Table 3. Track Geometry Standards 213.63 for Track Surface

Track Surface	**Class of Track**				
	1 (inches)	2 (inches)	3 (inches)	4 (inches)	5 (inches)
The runoff in any 31 feet of rail at the end of a raise may not be more than	3 ½	3	2	1 ½	1
The deviation from uniform profile on either rail at the mid-ordinate of a 62-foot chord may not be more than	3	2 ¾	2 ¼	2	1 ¼
The deviation from zero cross-level at any point on tangent or reverse cross-level elevation on curves may not be more than	3	2	1 ¾	1 ¼	1
The difference in cross-level between any two points less than 62 feet apart may not be more than* [1,2]	3	2 ¼	2	1 ¾	1 ½
*Where determined by engineering decision prior to the promulgation of this rule, due to physical restrictions on spiral length and operating practices an experience, the variation in cross-level on spirals per 31 feet may not be more than	2	1 ¾	1 ¼	1	¾

[1]Except as limited by §213.54(a), where the elevation at any point in a curve equals or exceeds 6 inches, the difference in cross-level within 62 feet between that point and a point with greater elevation may not be more than 1 ½ inches. (footnote 1 is applicable September 21, 1999.)
[2]However, to control harmonics on Class 2 through 5 jointed track with staggered joints, the cross-level differences shall not exceed 1 ¼ inches in all of six consecutive pairs of joints, as created by 7 low joints. Track with joints staggered less than 10 feet shall not considered as having staggered joints. Joints within the 7 low joints outside of the regular joint spacing shall not be considered as joints for purposes of this footnote. (Footnote 2 is applicable September 21, 1999.)

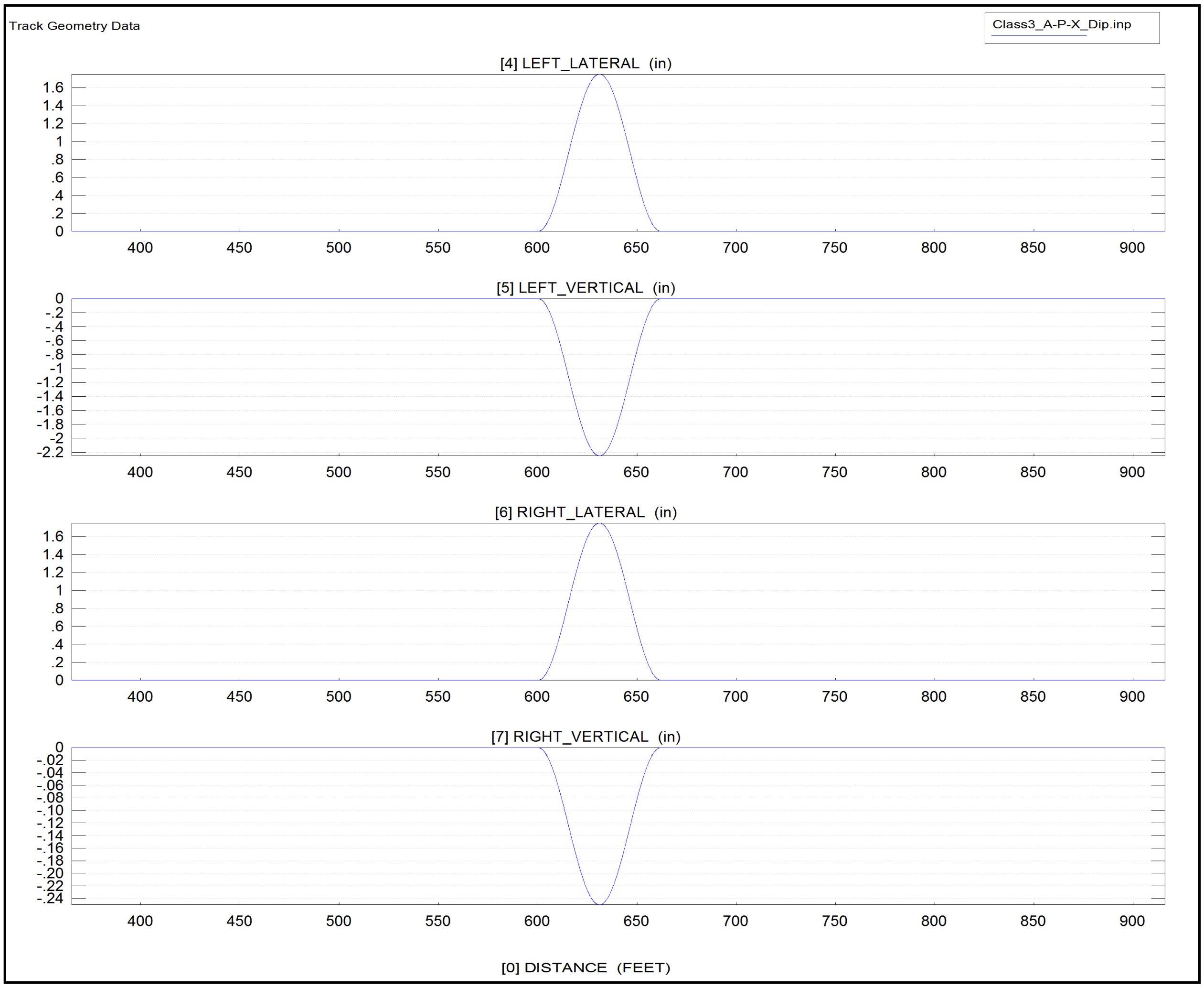

Figure 2. Example of Designed Track Geometry Deviations Used in Simulations

For each Class of track, the research team investigated a wide range of curvatures and mid-chord offsets (MCOs). Curvature was varied from tangent to 12 degrees in 2-degree increments, and MCOs were simulated for 31-foot and 62-foot chord lengths. For curved tracks, coefficients of friction representative of dry and lubricated track conditions were used and set to 0.5 and 0.2, respectively. The team simulated all track geometry defects as in-phase track deviations, present at the same locations. For this phase of work, track alignment, surface, and cross-level deviations were simulated. Several other parameters, such as runoff or ramps, were not included in the current study.

Operating speeds were not varied during the simulations and were set to maximum allowable limits based on each Class of track with a maximum cant deficiency of +3 for curvatures 2 through 12 degrees. Table 4 and Table 5 list the operating speeds used in the various simulations conducted in this study.

Table 4. Operating Speed Limits for Tangent Class of Track 1 Through 5

213.9 Classes of Track: Operating Speed Limits		
Over track that meets all of the requirements prescribed in this part for…	The maximum allowable operating speed (mph) for freight trains is	The maximum allowable operating speeds (mph) for passenger trains is
Excepted Track	**10**	NA
Class 1 Track	**10**	15
Class 2 Track	**25**	30
Class 3 Track	**40**	60
Class 4 Track	**60**	80
Class 5 Track	**80**	90

Table 5. Operating Speeds Used for Curved Tracks

Curvature	**Superelevation**	**-3**	**Balance**	**3**
Degrees	**Inches**	**Speed (mph)**	**Speed (mph)**	**Speed (mph)**
2.00	1.00	NA	26.92	**53.84**
4.00	3.00	0.00	32.97	**46.63**
6.00	4.00	15.54	31.08	**41.12**
8.00	4.00	13.46	26.92	**35.61**
10.00	4.00	12.04	24.08	**31.85**
12.00	4.00	10.99	21.98	**29.08**

An integral part of this project was to conduct vehicle performance assessment using criteria from AAR Chapter 11 (Table 6) and FRA 49 CFR 213.333 (Table 7). Both criteria provided a means to identify and compare vehicle dynamic performance issues in the presence of various track deviations and operating speeds. The research team examined vehicle dynamic performance results and analyzed them in terms of vehicle forces and accelerations exceeding pre-set criteria for safe operations. The team also analyzed these results in terms of "derailment incidents considered to be extreme exceedance cases"(determined from NUCARS simulations), which were quantified by large lateral and vertical rail displacements that would cause vehicles to leave the track without the possibility for re-railing. To determine the relative effect of each track geometry variable in the derailment cases, the team conducted a parametric analysis. The established a pass/fail/derail criterion from both sets of regulations, and track alignment, surface, and cross-level were, in turn, reduced from their maximum allowable values by 0.1-inch steps, and simulations rerun until vehicles would no longer derail.

Table 6. AAR Chapter 11 Criteria (Low Pass Filter 15 Hz using a 3-foot/50 msec Window)

Regime	**Section**	**Criterion**	**Limiting Value**
Hunting (empty)	11.7.2	minimum critical speed (mph) maximum lateral acceleration (g) standard deviation	70 1.5*** 0.26
Constant curving (empty and loaded)	11.7.3	95th percentile maximum wheel L/V or 95th percentile maximum axle sum L/V	1.0 1.5
Spiral (empty and loaded)	11.7.4	minimum vertical load (%) maximum wheel L/V or maximum axle sum L/V	10** 1.0* 1.5
Twist, Roll (empty and loaded)	11.8.2	maximum roll (deg)*** maximum axle sum L/V minimum vertical load (%)	6 1.5* 10**

Regime	Section	Criterion	Limiting Value
Pitch Bounce (loaded)	11.8.3	minimum vertical load (%)	10**
Yaw, Sway (loaded)	11.8.4	maximum L/V truck side maximum axle sum L/V	0.6* 1.5*
Dynamic curving (loaded)	11.8.5	maximum wheel L/V or maximum axle sum L/V maximum roll (deg)*** minimum vertical load (%)	1.0* 1.5** 6 10**
Vertical curve	11.9.2	to be added	
Horizontal curve	11.9.3	to be added	
*Not to exceed indicated value for a period greater than 50 milliseconds per exceedance. **Not to fall below indicated value for a period greater than 50 milliseconds per exceedance. ***Peak-to-peak ****See Paragraph 11.5.2.1 for allowable instrumented wheelset error bands.			

Table 7. 49 CFR 213.333 Criteria (Low Pass Filter of 25 Hz and 5-foot Window)

Vehicle/Track Interaction Safety Limits			
Wheel-Rail Forces			
Parameter	**Safety Limit**	**Filter/Window**	**Requirements**
Single Wheel Vertical Load Ratio	≥ 0.15	5 ft	No wheel of the vehicle shall be permitted to unload to less than 15 percent of the static vertical wheel load for 5 or more continuous feet.
Single Wheel L/V Ratio	$\leq \frac{\tan(\delta) - 0.5}{1 + 0.5\tan(\delta)}$	5 ft	The ratio of the lateral force that any wheel exerts on an individual rail to the vertical force exerted by the same wheel on the rail shall not be greater than the safety limit calculated for the wheel's flange angle (δ) for 5 or more continuous feet.
Net Axle Lateral L/V Ratio	$\leq 0.4 + \frac{5.0}{Va}$	5 ft	The net axle lateral force, in kips, exerted by any axle on the track shall not exceed a total of 5 kips plus 40 percent of the static vertical load that the axle exerts on the track for 5 or more continuous feet. Va = static vertical axle load (kips)
Truck Side L/V Ratio	≤ 0.6	5 ft	The ratio of the lateral forces that the wheels on one side of any truck exert on an individual rail to the vertical forces exerted by the same wheels on that rail shall not be greater than 0.6 for 5 or more continuous feet.

Carbody Accelerations			
Parameter	**Passenger Cars**	**Other Vehicles**	**Requirements**
Carbody Lateral (Transient)	$\leq 0.65\ g$ peak-to-peak 1 sec window Excludes peaks < 50 msec	$\leq 0.75\ g$ peak-to-peak 1 sec window Excludes peaks < 50 msec	The peak-to-peak accelerations, measured as the algebraic difference between the two extreme values of measured acceleration in any 1-second time period, excluding any peak lasting less than 50 milliseconds, shall not Exceed 0.65g and 0.75 g for passenger cars and other vehicles, respectively.

Carbody Accelerations			
Parameter	**Passenger Cars**	**Other Vehicles**	**Requirements**
Carbody Lateral (Sustained Oscillatory)	$\leq 0.10g\ RMS_1$[4] 4 sec window[3] 4 sec sustained	$\leq 0.12g\ RMS$[4] 4 sec window[3] 4 sec sustained	Sustained oscillatory lateral acceleration of the carbody shall not exceed the prescribed (root mean squared) safety limits of 0.10g and 0.12g for passenger cars and other vehicles, respectively. Root mean squared values shall be determined over a sliding 4-second window with linear trend removed and shall be sustained for more than 4 seconds.
Carbody Vertical (Transient)	$\leq 1.0g$ peak-to-peak 1 sec window[3] Excludes peaks < 50 msec	$\leq 1.25g$ peak-to-peak 1 sec window[3] Excludes peaks < 50 msec	The peak-to-peak accelerations, measured as the algebraic difference between the two extreme values of measured acceleration in any one second time period, excluding any peak lasting less than 50 milliseconds, shall not exceed 1.0g or 1.25g, as specified.
Carbody Vertical (Sustained Oscillatory)	$\leq 0.25g\ RMS_1$[4] 4 sec window[3] 4 sec sustained	$\leq 0.25g\ RMS$[4] 4 sec window[3] 4 sec sustained	Sustained oscillatory vertical acceleration of the carbody shall not exceed the prescribed (root mean squared) safety limit of 0.25g. Root mean squared values shall be determined over a sliding 4-second window with linear trend removed and shall be sustained for more than 4 seconds.
Truck Lateral Acceleration[5]			
Parameter	**Safety Limit**	**Filter/ Window**	**Requirements**
Truck Lateral	$\leq 0.30g\ RMS_1$[4]	2 sec window3 2 sec sustained	Truck hunting shall not develop below the maximum authorized speed. Truck hunting is defined as a sustained cyclic oscillation of the truck evidenced by lateral accelerations exceeding 0.3g root mean squared for more than 2 seconds. Root mean squared values shall be determined over a sliding 2-second window with linear trend removed.

[1] The lateral and vertical wheel forces shall be measured and processed through a low pass filter (LPF) with a minimum cut-off frequency of 25 Hz. The sample rate for wheel force data shall be at least 250 samples per second.
[2] Carbody accelerations in the vertical and lateral directions shall be measured by accelerometers oriented and located in accordance with § 213.333(k).
[3] Acceleration measurements shall be processed through an LPF with a minimum cut-off frequency of 10 Hz. The sample rate for acceleration data shall be at least 100 samples per second.
[4] RMS_l = RMS with linear trend removed.
[5] Truck lateral acceleration shall be measured on the truck frame by accelerometers oriented and located in accordance with § 213.333(k).

1.4 Scope

The primary aim of the NUCARS simulation work was to investigate single and combined track geometry deviation effects on vehicle dynamic performance for five vehicle types. The scope of the work is as follows:

- Develop NUCARS models for five freight vehicle types and run an extensive array of simulations over analytically defined track deviations, single and combined.

- Study and analyze the simulation instances that generated safety limit exceedances or derailments, using criteria of 49 CFR 213 and AAR Chapter 11.
- Run new simulations to resolve derailment (extreme exceedance) cases by reducing, in turn, track alignment, surface, and cross-level from their maximum allowable limits (0.1-inch steps) until derailments are cleared.
- Present a comprehensive summary of key issues and findings of simulation work conducted.

1.5 Organization of the Report

This report summarizes NUCARS simulation findings for the five vehicle types. The main body of the report consists of the NUCARS simulation work and is divided into the following parts:

1. Vehicle type selection for the simulation work: this section discusses how the research team selected the five vehicle types and gives detailed descriptions to vehicle parameters used to develop the models.
2. NUCARS simulation results: this section gives detailed descriptions of the simulation work performed for all the vehicle types run on all regimes using both CFR 213 and AAR Chapter 11 criteria.

Finally, the conclusions section outlines the way forward, recommending possible future work.

2. NUCARS Simulations

The research team selected five vehicle types for the NUCARS simulation work. Simulations focused on the effects of track geometry deviations over track Classes 1 through 5 on both tangent and curved tracks. Curvatures ranged from 2 to 12 degrees, in 2-degree increments. MCOs were simulated for 31-foot and 62-foot chord lengths. The simulations investigated single and combined track geometry deviation effects on vehicle dynamic performance on dry and lubricated tracks. For vehicle performance assessment, the team used criteria from AAR's Chapter 11 and FRA 49 CFR 213.333. They both provided a means to identify and compare vehicle performance issues in the presence of various track deviations and operating speeds.

2.1 Vehicle Type Selection

To conduct NUCARS simulations, the team analyzed the FRA Accident Incident database to select the vehicle types for these simulations. They based the vehicle type selection on the number of accidents per million miles. Figure 3 shows the accidents per million miles for freight vehicles available in the database, both loaded (red) and unloaded (blue). The selected vehicles were:

- Empty Tank car (T616)
- Loaded Tank car (T616)
- Empty Flat Car (F111)
- Loaded Flat Car (F111)
- Loaded Hopper Car (C114)

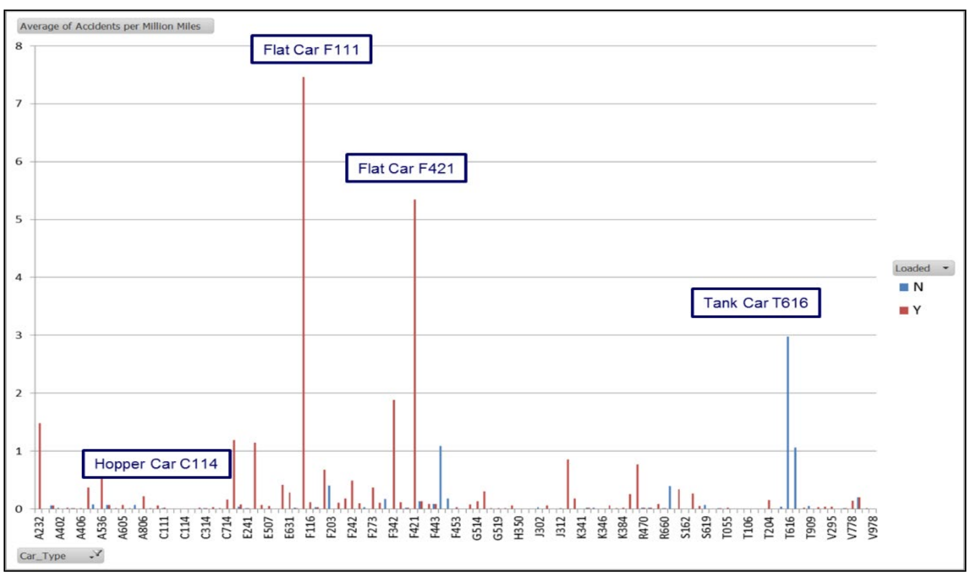

Figure 3. Accident Incident per Million Miles for Various Freight Cars (FRA Database)

The following is a description of model parameters of each vehicle:

- Empty/Loaded 100-ton Tank Car T616, 22,000-24,000 gallons, DOT 112
    - 72,930-pound empty, 225,540-pound loaded

- Variable damped
- 7-D5 outers, 6-D5 inners with double side coils
- 4500-pound pre-load constant contact long travel side bearings

- Empty/Loaded 70-ton Flat Car F111 less than 53 feet in length
  - 60,290-pound empty, 192,870-pound car
  - Constant damped
  - 7-D5 outers, 6-D5 inners with double side coils
  - 4500-pound pre-load constant contact long travel side bearings
- Empty/Loaded 110-ton Hopper Car
  - 48,000-pound empty, 286,000-pound car with
  - Variable damping
  - 6-D5 outers, 7-D6 inners, 4 D6A inner/inner with double side coils
  - 4500-pound pre-load constant contract long travel side bearings

Note that the researchers modernized all models to represent the required Constant Contact Side Bearings (CCSB) configurations.

Table 8 displays the modeled vehicle's carbody mass, mass moments of inertia for roll, pitch, and yaw, and center-of-gravity (CG) heights.

Table 8. Mass, Mass-Moments of Inertia and CG for Carbody

Car Type	Mass Slinches*	Ixx Slinch-In^2	Iyy Slinch-In^2	Ixx Slinch-In^2	CG Inches
Loaded Hopper	683.36	2.00E6	18.10E6	18.10E6	85.00
Loaded Tank	533.76	9.32E5	17.44E6	17.44E6	95.84
Loaded Flat	451.29	1.41E6	1.520E6	1.480E6	89.30
Empty Tank	138.50	0.377E6	5.09E6	5.09E68	91.90
Empty Flat	107.90	0.177E6	4.01E6	4.05E6	42.10

*1 slinch = 1 lb sec^2/in = 12 slugs (1 slug = 14.5939 kg)

Table 9 lists the suspension stiffness for each spring nest modeled vehicle.

Table 9. Vertical and Lateral Suspension Stiffness by Car Type

Car Type	Lateral lb/inch	Vertical lb/inch
Loaded Hopper	15,850	35,510
Loaded Tank	14,050	25,400
Loaded Flat	13,200	22,425
Empty Tank	10,850	25,400
Empty Flat	10,250	22,425

The NUCARS system files are provided in Appendix G of this report for ample information regarding every vehicle type.

2.2 Simulation Results

Figure 4 and Figure 5 depict graphical representations of all the possible simulation regimes that were conducted for each vehicle type on tangent and curved track of Classes 1 through 5. Note that for Class 1 and 2 tracks, 31-foot MCOs are not required.

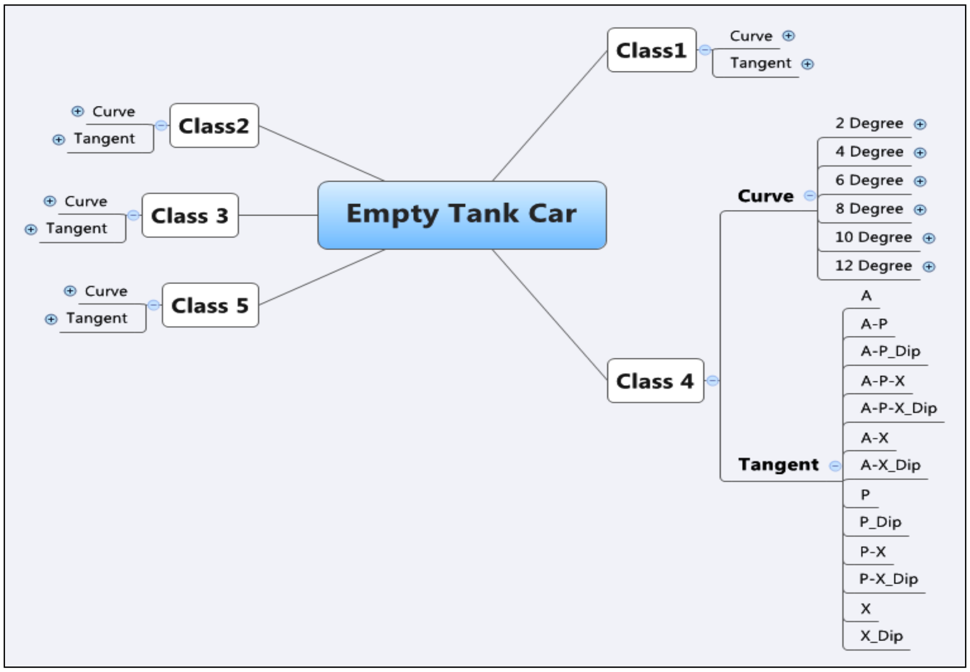

Figure 4. Simulation Permutations for One Vehicle Type

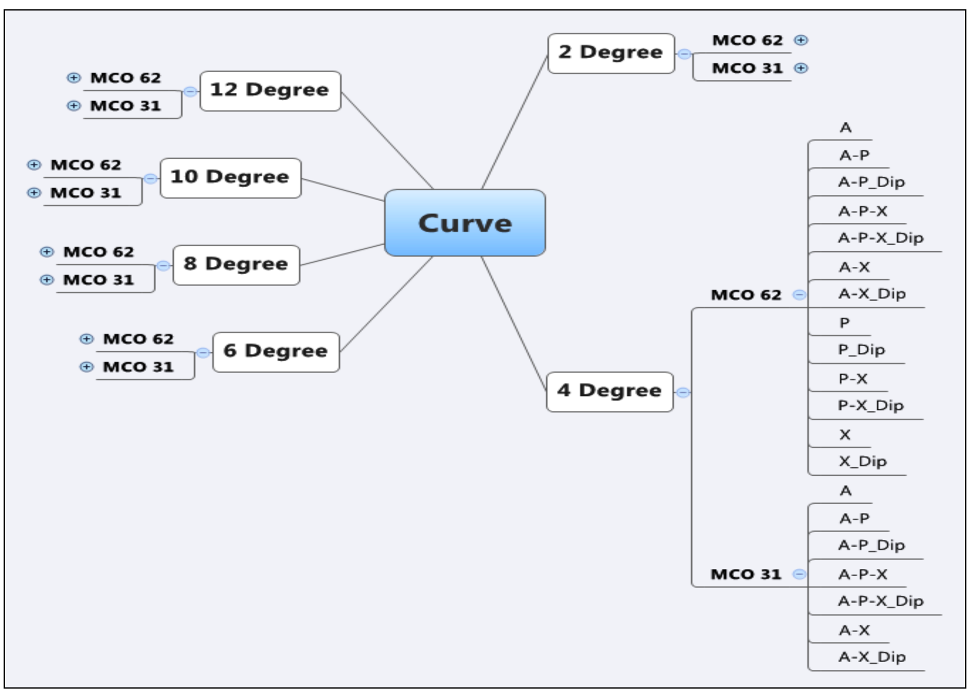

Figure 5. Expanded Simulation Permutations for One Vehicle Type

2.2.1 Tangent Track Simulations

Running all possible regimes on tangent track for the five vehicle types resulted in no derailment cases as determined from NUCARS simulations. However, exceedance cases (in terms of CFR 213 and AAR Chapter 11 criteria) were present, where one or more of the preset criteria were exceeded. Numerous pass cases were recorded in which no preset criterion was exceeded. Note that a low pass filter of 15-Hz and a 3-foot/50-mSec. exception window were applied to all Chapter 11 results, whereas a 25-Hz and 5-foot exception window were applied for CFR 213 results.

Figure 6 and Figure 7, respectively, summarize all tangent track simulation cases with all AAR Chapter 11 and CFR 213 criteria variables combined (i.e., forces and accelerations).

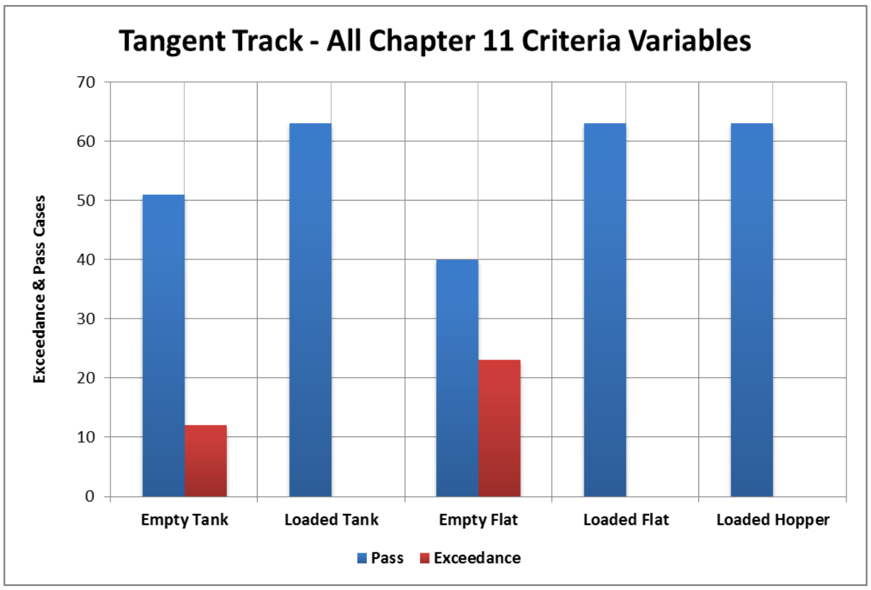

Figure 6. All AAR Chapter 11 Passes and Exceedance Cases

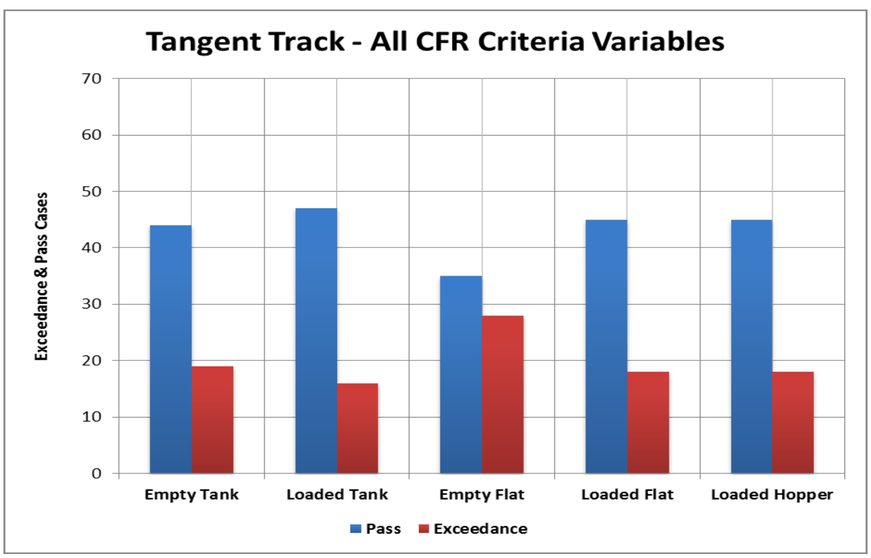

Figure 7. All CFR 213 Passes and Exceedance Cases

Since the variables used in AAR Chapter 11 and CFR 213 criteria are not analogous and cannot be practically compared in a side-by-side comparison, exceedances of the wheel force ratio of lateral to vertical (L/V) of both AAR Chapter 11 and CFR 213 were selected for a comparison. Figure 8 shows an L/V comparison. Using AAR Chapter 11 L/V criterion, a few exceedance cases were generated for both empty tank and empty flat cars. Applying the CFR 213 L/V criterion, no exceedance was generated for any of the vehicle types.

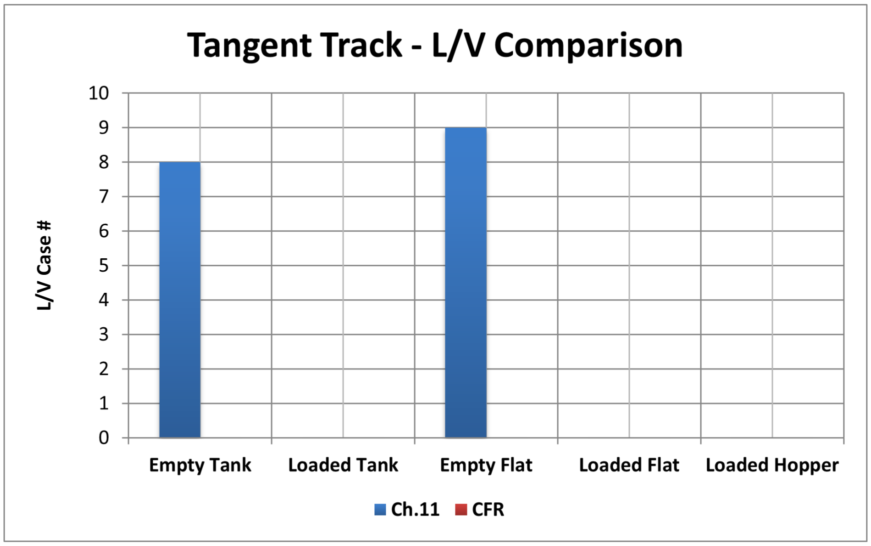

Figure 8. L/V Exceedance Comparison AAR Chapter 11 vs. CFR 213

2.2.2 Curved Track Simulations

In each simulation run for curves 2 through 12 degrees, the research team used coefficients of friction representative of dry and lubricated track conditions and set them o 0.5 and 0.2 respectively.

Based on AAR Chapter 11 and CFR 213 criteria, the researchers established a pass/fail/derail criterion to classify the various simulation results. A simulation instance in which one or more AAR Chapter 11 or CFR 213 criterion is exceeded is categorized as "fail"; it is "pass" if no criterion is exceeded. The extreme exceedance instances were derailment cases, as determined from NUCARS simulations, and were marked as such. Figure 9 and Figure 10 show the various pass/fail instances based on AAR Chapter 11 and CFR 213 criteria, respectively. Derailment cases were identical regardless of what criteria were applied.

The empty tank and empty flat cars presented the highest exceedance instances whether AAR Chapter 11 or CFR 213 criteria are applied. These two cars generated the highest numbers of derailment cases, which will be further analyzed and discussed in the following sections.

Figure 11 displays a comparison of ratio L/V exceedances obtained by applying AAR Chapter 11 and CFR 213 criteria. CFR 213 criteria shows fewer exceedances because of the use of a 25-Hz, low pass filter and the use of a 5-foot exception window.

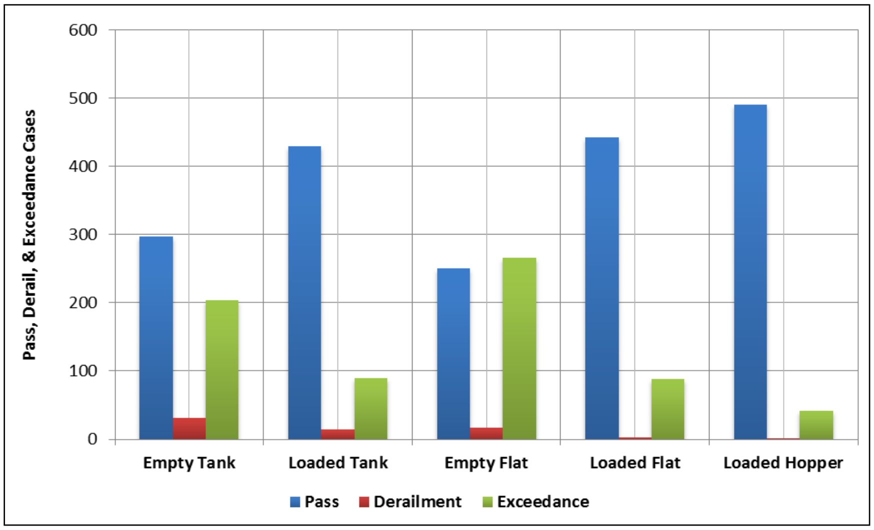

Figure 9. Curved Track Simulation Results for All AAR Chapter 11 Criteria Variables

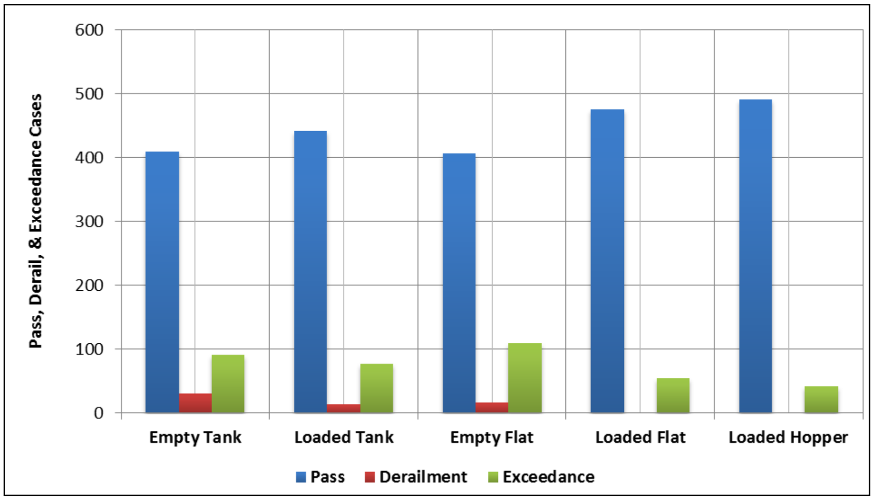

Figure 10. Curved Track Simulation Results for All CFR 213 Criteria Variables

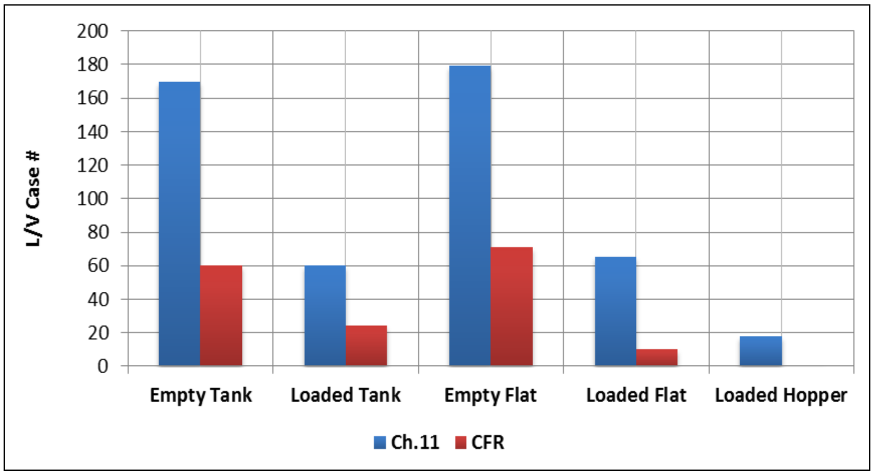

Figure 11. Dry Curve L/V Exceedance Comparison AAR Chapter 11 vs. CFR 213

All the simulation permutations that were run on curvatures 2 through 12 degrees for dry conditions were then rerun again using a coefficient of friction set to 0.2 for lubricated conditions. Lubricating the track resulted in eliminating all the derailment cases, and exceedance instances were significantly reduced. Figure 12 and Figure 13 illustrate the exceedance reduction where dry and lubricated conditions for ratio L/V exceedances are compared for the five vehicle types.

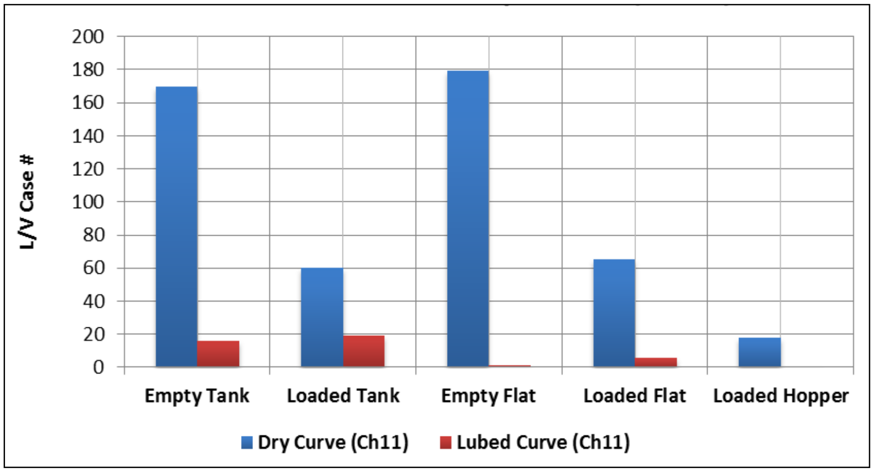

Figure 12. L/V Exceedance - Dry versus Lubricated Conditions on all Curves (AAR Chapter 11)

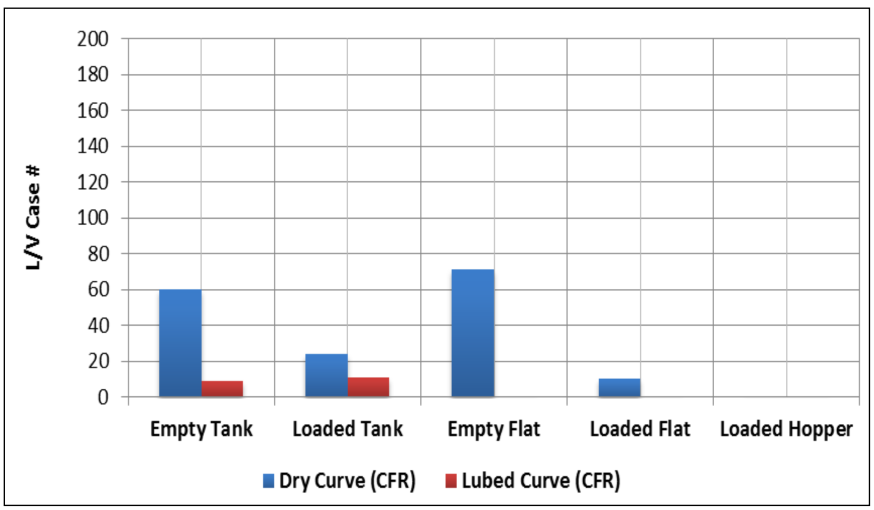

Figure 13. L/V Exceedance - Dry versus Lubricated Conditions on all Curves (CFR 213)

2.2.3 Derailment and Exceedance Instances

Given the enormous number of exceedances that resulted from the thousands of simulations, it was practically unfeasible to conduct a parametric study for all the cases based on both CFR 213 and AAR Chapter 11 Safety Standards. Since the derailment cases and exceedance cases occurred for both AAR Chapter 11 and CFR 213 standards, they were singled out for the parametric study in which the relative effects of track geometry variables were simulated and analyzed. The exceedance instances, including extreme exceedances/derailments, were analyzed by considering all the force and acceleration variables of both CFR 213 and AAR Chapter 11 standards. For the extreme exceedance instances, track alignment, surface, and cross-level were, in turn, reduced from their maximum allowable limits by 0.1-inch steps; the research team re-ran the simulations for each regime until derailments were resolved. All derailment instances occurred on dry curved track.

Empty Tank Car

The tank experienced derailments in 31 cases, the highest among the vehicles simulated. Nearly half of them happened on Class 1 track. Figure 14 shows a breakdown of the derailments the empty tank car experienced for each Class of Track.

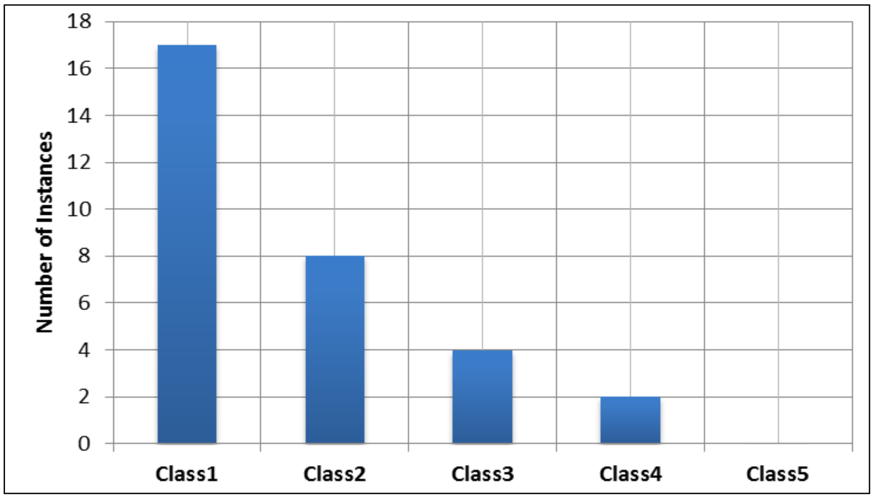

Figure 14. Empty Tank Car Extreme Exceedances/Derailments per Class of Track

Figure 15–18 breakdown the derailment cases by degree of curvature for Class 1 through Class 4; no derailments occurred in Class 5 tracks.

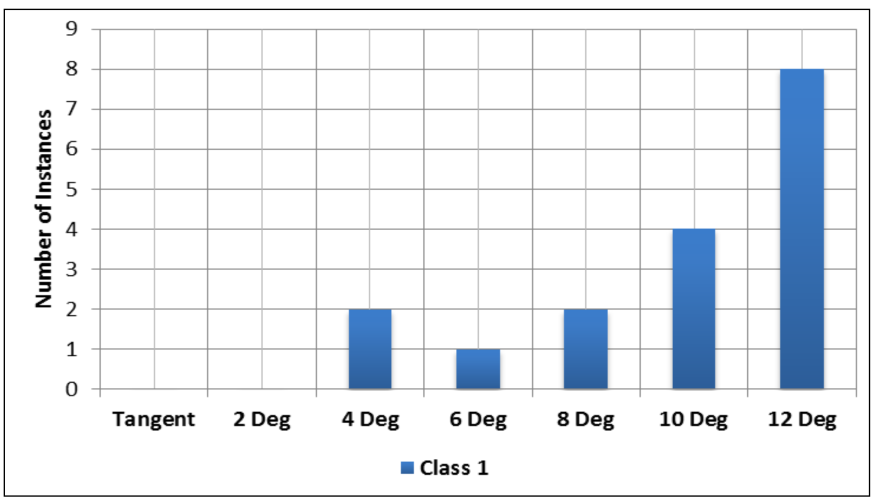

Figure 15. Empty Tank Car Extreme Exceedances/Derailments per Curve—Class 1

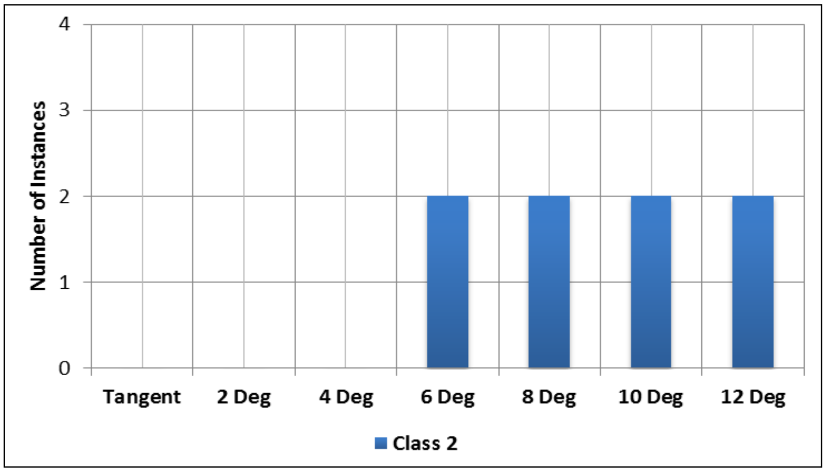

Figure 16. Empty Tank Car Extreme Exceedances/Derailments per Curve—Class 2

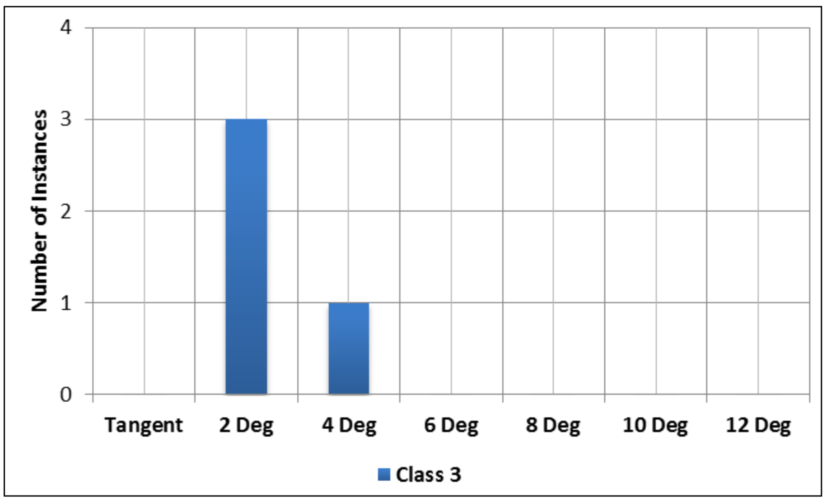

Figure 17. Empty Tank Car Extreme Exceedances/ Derailments per Curve—Class 3

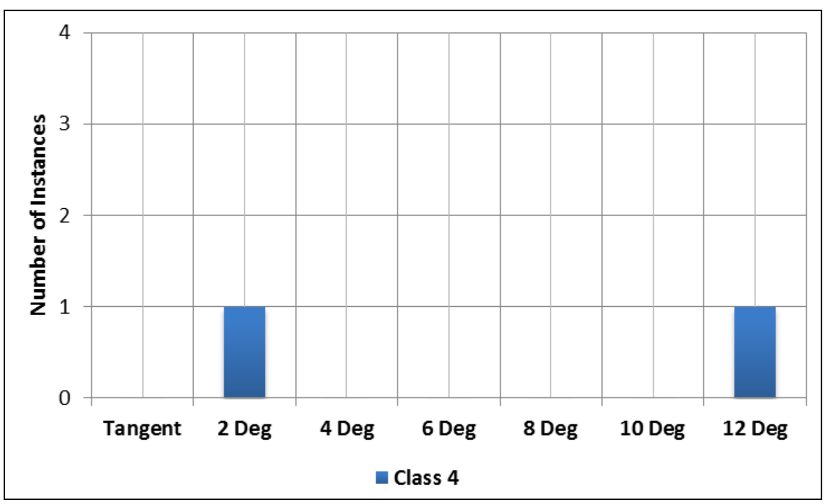

Figure 18. Empty Tank Car Extreme Exceedances/Derailments per Curve—Class 4

Due to the high number of cases, Appendices A, B, and C contain detailed derailment tables for Track Class 1, Class 2, and combined Classes 3 and 4, respectively.

Table 10 is an example derailment table. Each row shows the Class of track, derailment number, curvature, MCO used, speed, regime abbreviation (APX), allowable track geometry limits for left alignment (L Align), left profile (L Profile), right alignment (R Align), right profile (R Profile) cross-level (X-level), if the perturbation was a dip (meaning down on the high rail of a curve) or a bump (meaning upward on the high rail) and if the derailment cleared/passed. Note: all alignments were simulated as outward on all curves; no inward alignment deviations were simulated.

Table 10. Example Derailment Table

Class	Derail #	Curve	MCO	Speed	Regime	L Align	L Profile	R Align	R Profile	X-level	Dip/Bump	Derail Cleared
1	1	4	62	10	A P X	5	1.5	5	-1.5	-3	Dip	No
					A P X	2.2	1.5	2.2	-1.5	-3	Dip	Yes
					A P X	5	-0.7	5	0.7	-1.4	Dip	Yes
1	2	4	62	10	A X	5	-1.5	5	1.5	-3	Dip	No
					A X	4.9	-1.5	4.9	1.5	-3	Dip	Yes
					A X	5	-1.45	5	1.45	-2.9	Dip	Yes

The subsequent row(s) represent the simulation(s) of reduced geometry variables aimed at preventing the vehicle from derailing. Most regimes with reduced geometry succeeded at creating new track conditions that prevented the car from derailing. There were, however, three down and out Class 1 regimes (Derailments 6, 11, and 13) in which derailments were not totally resolved. By reducing the track alignment down to 0 inch while maintaining the profile and cross-level at the maximum allowable limits, the empty tank car still derailed in simulations. Nonetheless, these derailment cases were resolved by reducing profile and cross-level while maintaining track alignment at its maximum allowable limits. This may indicate that track alignment deviations are less dominant in causing adverse dynamic behavior. Influence of operating speed variations on vehicle dynamics were not investigated since speed was always set to maximum track speed throughout the study.

Loaded Tank Car

The loaded tank car had derailment instances in 14 cases, all Class 1 regimes. Figure 19 and Figure 20 show a breakdown of derailments the loaded tank car experienced in each class of track. Derailment instances for loaded tank car simulations are compiled in Appendix D.

The loaded tank car also experienced six derailments, in cases 3, 4, 7, 8, 11, and 12. These were alignment related. In each of these six regimes, track alignment was reduced to 0 inch while maintaining the profile and cross-level at their maximum allowable limits, yet the loaded tank car derailed. These cases were resolved by reducing profile and cross-level while maintaining track alignment at its maximum allowable limit. This may indicate that track alignment deviations are less dominant in causing adverse dynamic behavior.

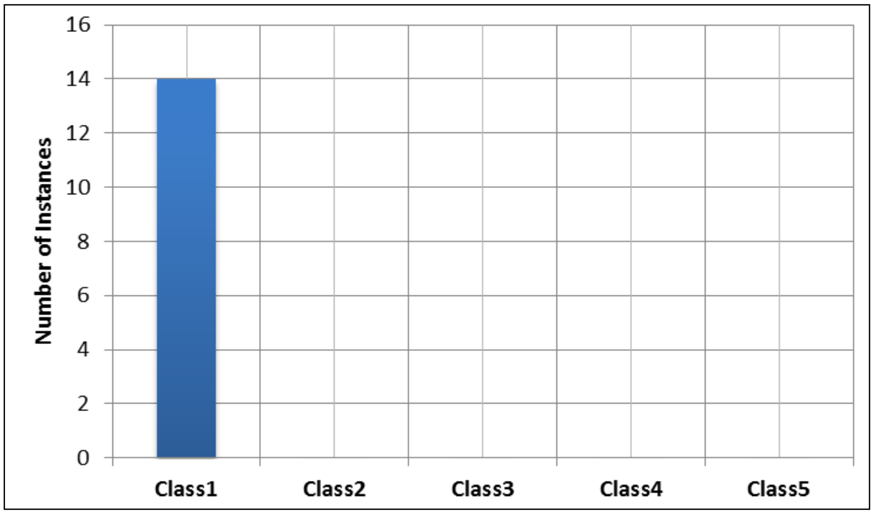

Figure 19. Loaded Tank Car Extreme Exceedances/Derailments per Class of Track

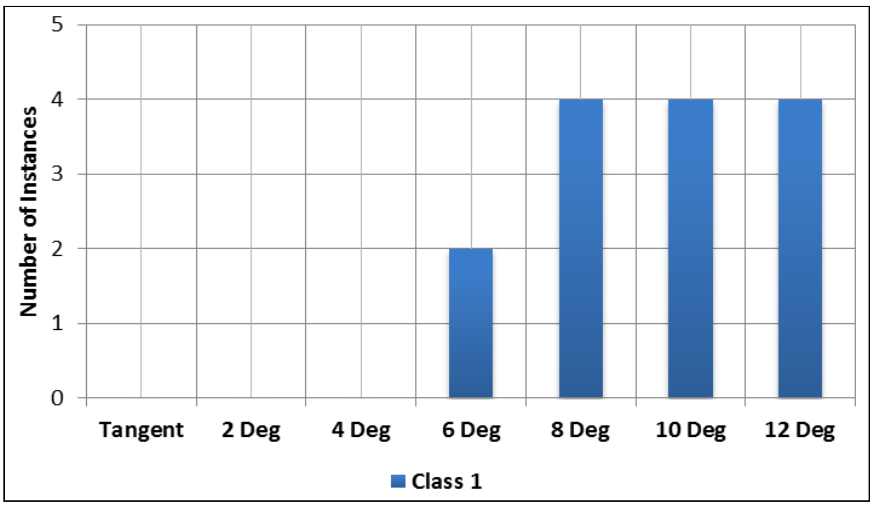

Figure 20. Loaded Tank Car Extreme Exceedances/Derailments per Curve—Class 1

Empty Flat Car

The empty flat car experienced 17 derailments, the second highest after the empty tank car. Figure 21 shows the number of derailments the empty flat car experienced in each class of track. Figure 22 through Figure 25 break down the derailment cases by degree of curvature for Class 1 through Class 4. No derailments were recorded in Class 5 simulations.

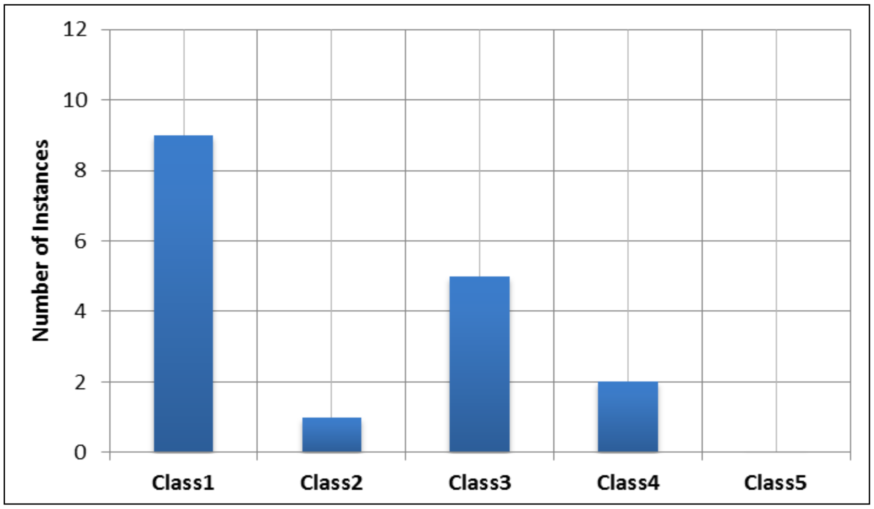

Figure 21. Empty Flat Car Extreme Exceedances/Derailments per Class of Track

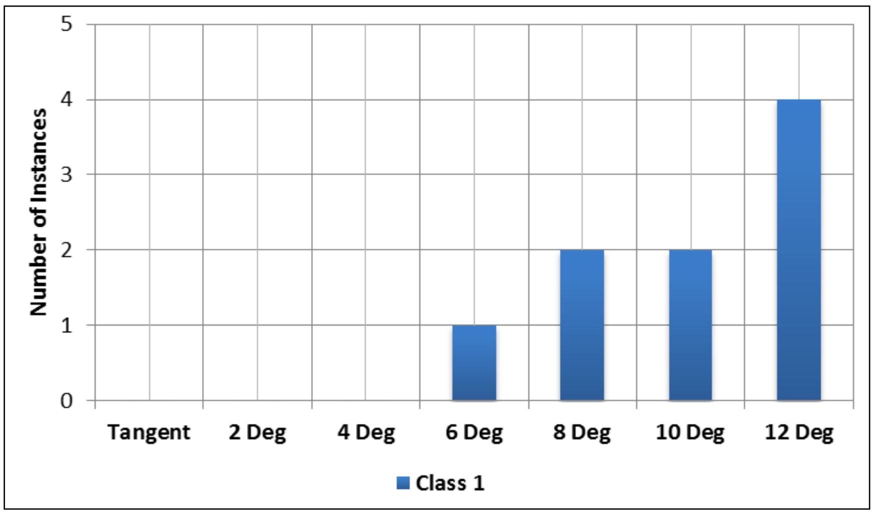

Figure 22. Empty Flat Car Extreme Exceedances/Derailments per Curve—Class 1

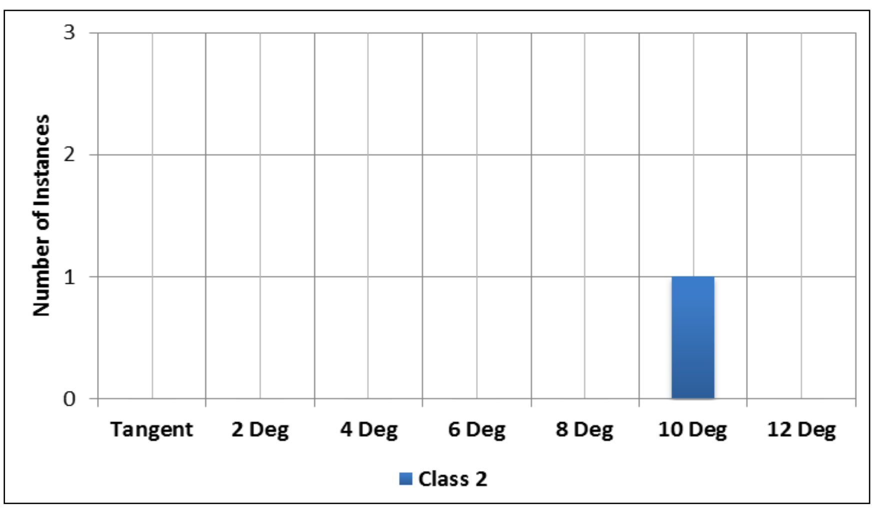

Figure 23. Empty Flat Car Extreme Exceedances/Derailments per Curve—Class 2

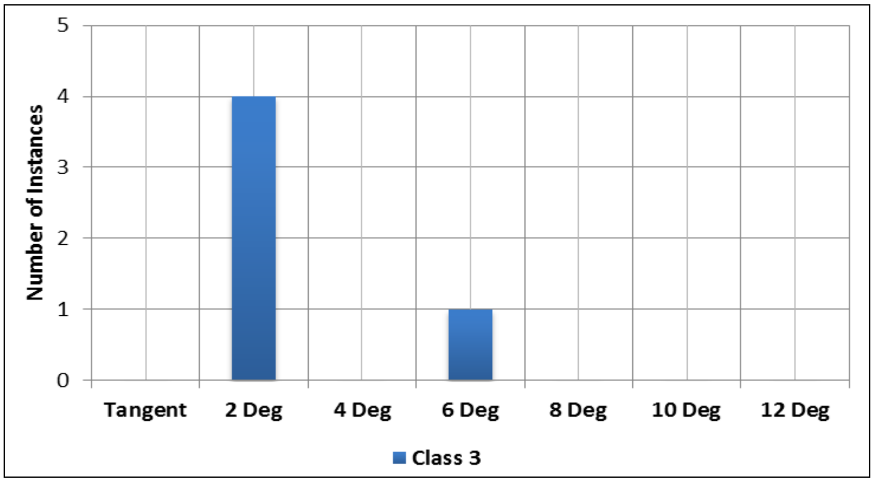

Figure 24. Empty Flat Car Extreme Exceedances/Derailments per Curve—Class 3

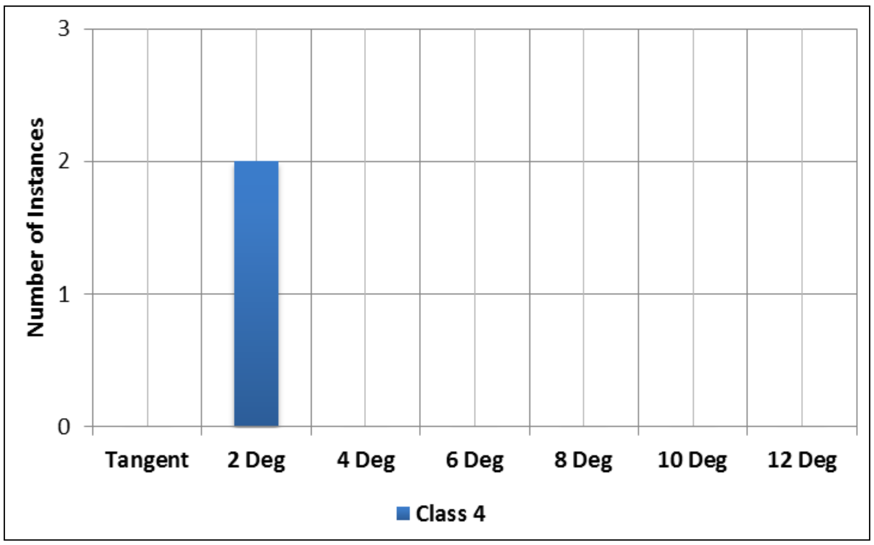

Figure 25. Empty Flat Car Extreme Exceedances/Derailments per Curve—Class 4

Derailment instances for Empty Flatcar simulations are compiled in Appendix E and Appendix F. Detailed information about each derailment regime and the track geometry combinations were resolved each derailment case.

Like the tank car, there were two down and out Class 1 regimes (Derailment numbers 6 and 7) in which derailments continued occurring after reducing the track alignment to 0 inch while profile and cross-level were set to their maximum allowable limits. These two derailment regimes, however, cleared after reducing the profile and cross-level while maintaining alignment at its maximum limit. Again, this may indicate that track alignment deviations are less dominating in causing adverse dynamic behavior.

Loaded Flat Car

The flat car experienced two derailments: a down and out regime derailment on Class 3 track and a track up and out regime on Class 4 track. Table 11 lists the details of the two regimes that caused the flat car to derail.

Table 11. Loaded Flat Car Derailments/Extreme Exceedance Instances

Class	Derail#	Curve	MCO	Speed	Regime	L Align	L Profile	R Align	R Profile	X-level	Dip/Bump	Derail Cleared
3	1	2	31	40	A X	1.25	-1	1.25	1	-2	Dip	No
					A X	1.1	-1	1.1	1	-2	Dip	Yes
					A X	1.25	-0.95	1.25	0.95	-1.9	Dip	Yes
4	2	2	31	46.63	A P	1	2	1	2	0	Bump	No
					A P	0.9	2	0.9	2	0	Bump	Yes
					A P	1	1.8	1	1.8	0	Bump	Yes

Loaded Hopper Car

The loaded hopper car had one regime that caused a derailment: a down and out regime on Class 1 track. Table 12 shows the regime details.

Table 12. Loaded Hopper Car Derailment/Extreme Exceedance Instances

Class	Derail#	Curve	MCO	Speed	Regime	L Align	L Profile	R Align	R Profile	X-level	Dip/Bump	Derail Cleared
1	1	10	62	10	A P X	5	-1.5	5	1.5	-3	Dip	No
					A P X	4.7	-1.5	4.7	1.5	-3	Dip	Yes
					A P X	5	-1.35	5	1.35	-2.7	Dip	Yes

3. General Observations

The team made the following general observations:

- The thoroughly studied extreme dynamic responses that resulted in derailments in simulations also represented exceedance instances based on both CFR 213 and AAR Chapter 11 standards.
- Most of the derailments occurred in Class 1 track. The derailments mostly occurred in combinations of the maximum permissible track geometry deviations. Derailments caused by single track geometry deviations alone were very rare. These conditions were observed in all track classes.
- Class 5 was the only track class over which no derailment occurred by any of the five vehicles simulated, regardless of the track geometry deviation(s) used.
- The operating speed used in the simulations was the maximum allowable speed for each class of track. The research team did not study the operating speed effects on derailment cases. Rerunning derailment regime simulations with reduced speed (0.5- or 1-mph steps) could have helped determine the potential effects of speed on vehicle dynamics with the various regimes simulated, and determine how it could have helped resolve some of the derailment cases.
- The three car types that experienced the most significant derailment cases were empty tank car, empty flat car, and loaded tank car. Most derailment cases experienced by the empty tank and empty flat cars occurred in regimes in which cross-level perturbations were dip, meaning down on the high rail of the curve. The loaded tank car, however, experienced all the derailments cases in presence of upward cross-level perturbations (bump).
- No derailment was recorded on tangent track by any vehicle type. All derailments occurred on curvatures, with the highest number of instances in Class 1 track. For empty cars, the sharper the curvature, the higher the number of derailments experienced. The loaded tank car trended similarly, except that the number of derailments was equal for curvatures 8 through 12.
- The team used MCO 31-foot and MCO 62-foot chord lengths in simulations. All track Class 1 and Class 2 derailments occurred with MCO 62-foot track deviations. Track Class 3 and Class 4 derailments all occurred with MCO 31-foot deviations except for one Track Class 4 instance in which the empty tank car derailed with MCO 62-foot track deviations.

4. Conclusion and Future Research

To assess vehicle performance of five vehicle types over analytically defined track perturbations, FRA sponsored a research team to conduct an all-inclusive parametric study using NUCARS. They used AAR Chapter 11 and 49 CFR 213 criteria for the vehicle performance assessment. The following vehicle types were selected based on the number of accidents per million miles:

- Empty and loaded tank cars
- Empty and loaded flat cars
- Loaded hopper car

The researchers used a matrix of the maximum allowable limits for track alignment, surface, and cross-level deviations over track Classes 1 through 5. The simulation matrix included single track deviations and synchronized, combined track deviations. They ran the simulation matrix for every vehicle type. For each class of track and each vehicle type, curvature was varied from tangent to 12 degrees in 2-degree increments, and MCOs were simulated for 31-foot and 62-foot chord lengths. Coefficients of friction representative of dry and lubricated track conditions were used and set to 0.5 and 0.2 respectively.

To determine the relative effect of each track geometry variable in the derailment/extreme exceedance cases, the team established a pass/fail/derail criterion, and reduced track alignment, surface, and cross-level, in turn, from their maximum values by 0.1-inch steps. They ran the simulations until the vehicle no longer experienced adverse dynamic responses.

4.1 Simulations Results

The research team did not record any derailments on tangent track in simulations with any vehicle. Following AAR Chapter 11 and CFR 213 standards, empty tank and empty flat cars generated more exceedances than the other vehicle types. For a close comparison between CFR 213 and AAR Chapter 11 standards, the research team used the L/V ratio criterion. Based on AAR Chapter 11 criteria, both empty tank and empty flat cars generated a few exceedance cases. Using CFR 213 criteria, none of the vehicle types generated any exceedance.

For curved track, the empty tank and empty flat cars had the highest number of exceedance instances using both AAR Chapter 11 and CFR 213 criteria. These two cars also had the highest numbers of extreme exceedances and derailment cases. The car with the least adverse dynamic behavior was the loaded hopper car (the base comparison car). The research team ran all the simulation regimes run on dry curves again in lubricated conditions, with coefficient of friction set to 0.2. Lubricating the curved track eliminated all the derailment cases and significantly reduced the exceedance instances.

The team conducted thorough simulation work to determine the relative effect of each track geometry variable in the derailment and extreme exceedance cases in order to resolve them. They reduced track alignment, surface, and cross-level, in turn, from their maximum values by 0.1-inch steps, and derived track geometry combinations resolving all derailment instances for all the vehicle types.

4.2 Recommendations for Future Work

The simulation work shows that the tank car, empty and loaded, is the most prone to generating adverse dynamic response over the various regimes simulated, based on both CFR 213 and AAR Chapter 11 criteria. Further simulation work is recommended as follows:

- Shift simulation focus to the empty and loaded tank cars.
- Perform shake and bake tests on tank car type to update and refine models.
- Evaluate larger range of amplitudes for each Class of Track standard for track alignment, profile, and cross-level.
- Simulate regimes beyond allowable FRA standards over tangent and curved track with track deviations of 2 through 12 degrees with 2-degree steps. Typical regimes to be simulated might be some or all of the following combinations (single or repeated deviations):
    - Alignment
    - Alignment and Profile
    - Alignment and Cross-level
    - Alignment, Profile, and Cross-level
    - Profile
    - Profile and Cross-level
    - Cross-Level

As part of the study, investigate speed effects on vehicle dynamic performance alongside the track deviations. Six operating speeds per regime are proposed for empty and loaded tank cars. Simulate maximum speed for each curve and class of track for the critical frequencies concerning the following rigid body modes of vibration:

- Bounce
- Pitch
- Yaw
- Lower Center Roll
- Upper Center Roll

Ample information is provided in Appendix H regarding critical frequencies, critical speeds, and various wavelengths for the empty and loaded tank cars, as well as for the other vehicle types simulated in this study.

4.2.1 Track Quality Standard

Quantify the percentage of each track parameter/variable (including speed) generating poor vehicle performance. The goal of this effort will help develop more accurate track quality standards.

4.2.2 Analysis Utility

Build a utility to automate the evaluation and analysis of parameter sensitivity to facilitate the simulation efforts, given the high number of variables/permutations typically involved in parametric simulations.

References

[1] Association of American Railroads. Chapter 11, Service-worthiness tests and analyses for new freight cars. *Manual of Standards and Recommended Practices: Design, Fabrication and Construction of Freight Cars, Standard M-1001, Section C-II.*

[2] 49 CFR Part 213 Subpart C, Track Geometry.

Appendix A.
Empty Tank Class 1 Derailment/Extreme Exceedance Instances

Class	Derail #	Curve	MCO	Speed	Regime	L Align	L Profile	R Align	R Profile	X-level	Dip/Bump	Derail Cleared
1	1	4	62	10	A P X	5	1.5	5	-1.5	-3	Dip	No
					A P X	2.2	1.5	2.2	-1.5	-3	Dip	Yes
					A P X	5	-0.7	5	0.7	-1.4	Dip	Yes
1	2	4	62	10	A X	5	-1.5	5	1.5	-3	Dip	No
					A X	4.9	-1.5	4.9	1.5	-3	Dip	Yes
					A X	5	-1.45	5	1.45	-2.9	Dip	Yes
1	3	6	62	10	A X	5	-1.5	5	1.5	-3	Dip	No
					A X	4	-1.5	4	1.5	-3	Dip	Yes
					A X	5	-1.4	5	1.4	-2.8	Dip	Yes
1	4	8	62	10	A P X	5	-1.5	5	1.5	-3	Dip	No
					A P X	1	-1.5	1	1.5	-3	Dip	Yes
					A P X	5	-0.65	5	0.65	-1.3	Dip	Yes
1	5	8	62	10	A X	5	-1.5	5	1.5	-3	Dip	No
					A X	4.6	-1.5	4.6	1.5	-3	Dip	Yes
					A X	5	-1.35	5	1.35	-2.7	Dip	Yes
1	6	10	62	10	A P X	5	-1.5	5	1.5	-3	Dip	No
					A P X	0	-1.5	0	1.5	-3	Dip	No
					A P X	5	-1	5	1	-2	Dip	Yes
1	7	10	62	10	A X	5	-1.5	5	1.5	-3	Dip	No
					A X	4.6	-1.5	4.6	1.5	-3	Dip	Yes
					A X	5	-1.4	5	1.4	-2.8	Dip	Yes
1	8	10	62	10	P X	0	-1.5	0	1.5	-3	Dip	No
					P X	0	-1.3	0	1.3	-2.6	Dip	Yes
1	9	10	62	10	X	0	-1.5	0	1.5	-3	Dip	No
					X	0	-1.3	0	1.3	-2.6	Dip	Yes
1	10	12	62	10	A P X	5	1.5	5	-1.5	3	Bump	No
					A P X	4.5	1.5	4.5	-1.5	3	Bump	Yes
					A P X	5	1.35	5	-1.35	2.7	Bump	Yes
1	11	12	62	10	A P X	5	-1.5	5	1.5	-3	Dip	No
					A P X	0	-1.5	0	1.5	-3	Dip	No
					A P X	5	-0.75	5	0.75	-1.5	Dip	Yes
1	12	12	62	10	A X	5	1.5	5	-1.5	3	Bump	No
					A X	4.5	1.5	4.5	-1.5	3	Bump	Yes
					A X	5	1.35	5	-1.35	2.7	Bump	Yes
1	13	12	62	10	A X	5	-1.5	5	1.5	-3	Dip	No
					A X	0	-1.5	0	1.5	-3	Dip	No
					A X	5	-0.75	5	0.75	1.5	Dip	Yes
1	14	12	62	10	P X	0	1.5	0	-1.5	3	Bump	No
					P X	0	1.45	0	-1.45	2.9	Bump	yes
1	15	12	62	10	P X	0	-1.5	0	1.5	-3	Dip	No
					P X	0	-0.8	0	0.8	-1.6	Dip	yes
1	16	12	62	10	X	0	1.5	0	-1.5	3	Bump	No
					X	0	1.45	0	-1.45	2.9	Bump	yes
1	17	12	62	10	X	0	-1.5	0	1.5	-3	Dip	No
					X	0	-0.8	0	0.8	-1.6	Dip	Yes

Figure A 1. Empty Tank Class 1 Derailment/Extreme Exceedance Instances

Appendix B.
Empty Tank Class 2 Derailment/Extreme Exceedance Instances

Class	Derail #	Curve	MCO	Speed	Regime	L Align	L Profile	R Align	R Profile	X-level	Dip/Bump	Derail Cleared
2	18	6	62	25	A P X	3	-2.75	3	-0.5	-2.25	Dip	No
					A P X	2.7	-2.75	2.7	-0.5	-2.25	Dip	Yes
					A P X	3	-2.05	3	-0.2	-2.25	Dip	Yes
					A P X	3	-2.75	3	-0.9	-1.85	Dip	Yes
2	19	6	62	25	A X	3	-1.125	3	1.125	-2.25	Dip	No
					A X	2.7	-1.125	2.7	1.125	-2.25	Dip	Yes
					A X	3	-0.9	3	0.9	-1.8	Dip	Yes
2	20	8	62	25	A P X	3	-2.75	3	-0.5	-2.25	Dip	No
					A P X	2.4	-2.75	2.4	-0.5	-2.25	Dip	Yes
					A P X	3	-2.05	3	-0.2	-2.25	Dip	Yes
					A P X	3	-2.75	3	-0.6	-2.15	Dip	Yes
2	21	8	62	25	A X	3	-1.125	3	1.125	-2.25	Dip	No
					A X	2.4	-1.125	2.4	1.125	-2.25	Dip	Yes
					A X	3	-0.85	3	0.85	-1.7	Dip	Yes
2	22	10	62	25	A P X	3	-2.75	3	-0.5	-2.25	Dip	No
					A P X	1.9	-1.75	1.9	-0.5	-2.25	Dip	Yes
					A P X	3	-2.1	3	-0.15	-2.25	Dip	Yes
					A P X	3	-2.75	3	-0.8	-1.95	Dip	Yes
2	23	10	62	25	A X	3	-1.125	3	1.125	-2.25	Dip	No
					A X	1.9	-0.125	1.9	1.125	-2.25	Dip	Yes
					A X	3	-0.95	3	0.95	-1.9	Dip	Yes
2	24	12	62	25	A P X	3	-2.75	3	-0.5	-2.25	Dip	No
					A P X	2.5	-2.75	2.5	-0.5	-2.25	Dip	Yes
					A P X	3	-2.7	3	-0.45	-2.25	Dip	Yes
					A P X	3	-2.75	3	-0.6	-2.15	Dip	Yes
2	25	12	62	25	X	0	-1.125	0	1.125	-2.25	Dip	No
					X	0	-0.9	0	0.9	-1.8	Dip	Yes

Figure B 1. Empty Tank Class 2 Derailment/Extreme Exceedance Instances

Appendix C.
Empty Tank Class 3 and 4 Derailment/Extreme Exceedance Instances

Class	Derail #	Curve	MCO	Speed	Regime	L Align	L Profile	R Align	R Profile	X-level	Dip/Bump	Derail Cleared
3	26	2	31	40	A P X	1.25	-2.25	1.25	-0.25	-2	Dip	No
					A P X	1.1	-2.25	1.1	-0.25	-2	Dip	Yes
					A P X	1.25	-1.75	1.25	0.25	-2	Dip	Yes
					A P X	1.25	-2.25	1.25	-0.6	-1.65	Dip	Yes
3	27	2	31	40	A X	1.25	-1	1.25	1	-2	Dip	No
					A X	1.1	-1	1.1	1	-2	Dip	Yes
					A X	1.25	-0.85	1.25	0.85	-1.7	Dip	Yes
3	28	2	31	40	A P X	1.25	-2.25	1.25	-0.25	-2	Dip	No
					A P X	1.1	-2.25	1.1	-0.25	-2	Dip	Yes
					A P X	1.25	-1.75	1.25	0.25	-2	Dip	Yes
					A P X	1.25	-2.25	1.25	-0.6	-1.65	Dip	Yes
3	29	4	31	40	A P X	1.25	-2.25	1.25	-0.25	-2	Dip	No
					A P X	1.1	-2.25	1.1	-0.25	-2	Dip	Yes
					A P X	1.25	-2.05	1.25	-0.05	-2	Dip	Yes
					A P X	1.25	-2.25	1.25	-0.6	-1.65	Dip	Yes
4	30	2	31	53.84	A X	1	-0.875	1	0.875	-1.75	Dip	No
					A X	0.9	-0.875	0.9	0.875	-1.75	Dip	Yes
					A X	1	-0.45	1	0.45	-0.9	Dip	Yes
4	31	12	62	29.08	P X	0	-2	0	-0.25	-1.75	Dip	No
					P X	0	-1.95	0	-0.2	-1.75	Dip	Yes
					P X	0	-2	0	-1.25	-0.75	Dip	Yes

Figure C 1. Empty Tank Class 3 and 4 Derailment/Extreme Exceedance Instances

Appendix D.
Loaded Tank Derailment/Extreme Exceedance Instances (All Class 1)

Class	Derail #	Curve	MCO	Speed	Regime	L Align	L Profile	R Align	R Profile	X-level	Dip/Bump	Derail Cleared
1	1	6	62	10	P X	0	1.5	0	-1.5	3	Bump	No
					P X	0	1.45	0	-1.45	2.9	Bump	Yes
1	2	6	62	10	X	0	1.5	0	-1.5	3	Bump	No
					X	0	1.45	0	-1.45	2.9	Bump	Yes
1	3	8	62	10	A P X	5	1.5	5	-1.5	3	Bump	No
					A P X	0	1.5	0	-1.5	3	Bump	No
					A P X	5	1.4	5	-1.4	2.8	Bump	yes
1	4	8	62	10	A X	5	1.5	5	-1.5	3	Bump	No
					A X	0	1.5	0	-1.5	3	Bump	No
					A X	5	1.4	5	-1.4	2.8	Bump	yes
1	5	8	62	10	P X	0	1.5	0	-1.5	3	Bump	No
					P X	0	1.35	0	-1.35	2.7	Bump	yes
1	6	8	62	10	X	0	1.5	0	-1.5	3	Bump	Yes
					X	0	1.35	0	-1.35	2.7	Bump	No
1	7	10	62	10	A P X	5	1.5	5	-1.5	3	Bump	No
					A P X	0	1.5	0	-1.5	3	Bump	No
					A P X	5	1.4	5	-1.4	2.8	Bump	yes
1	8	10	62	10	A X	5	1.5	5	-1.5	3	Bump	No
					A X	0	1.5	0	-1.5	3	Bump	No
					A X	5	1.4	5	-1.4	2.8	Bump	yes
1	9	10	62	10	P X	0	1.5	0	-1.5	3	Bump	No
					P X	0	1.3	0	-1.3	2.6	Bump	yes
1	10	10	62	10	X	0	1.5	0	-1.5	3	Bump	No
					X	0	1.3	0	-1.3	2.6	Bump	yes
1	11	12	62	10	A P X	5	1.5	5	-1.5	3	Bump	No
					A P X	-8.3E-16	1.5	-8.3E-16	-1.5	3	Bump	No
					A P X	5	1.35	5	-1.35	2.7	Bump	yes
1	12	12	62	10	A X	5	1.5	5	-1.5	3	Bump	No
					A X	-1.3E-15	1.5	-1.3E-15	-1.5	3	Bump	No
					A X	5	1.35	5	-1.35	2.7		yes
1	13	12	62	10	P X	0	1.5	0	-1.5	3	Bump	No
					P X	0	1.35	0	-1.35	2.7	Bump	yes
1	14	12	62	10	X	0	1.5	0	-1.5	3	Bump	No
					X	0	1.35	0	-1.35	2.7	Bump	yes

Figure D 1. Loaded Tank Derailment/Extreme Exceedance Instances (All Class 1)

Appendix E.
Empty Flat car Derailment/Extreme Exceedance Instances (Class 1)

Class	Derail #	Curve	MCO	Speed	Regime	L Align	L Profile	R Align	R Profile	X-level	Dip/Bump	Derail Cleared
1	1	6	62	10	A P X	5	-1.5	5	1.5	-3	Dip	No
					A P X	3	-1.5	3	1.5	-3	Dip	Yes
					A P X	5	-0.75	5	0.75	-1.5	Dip	Yes
1	2	8	62	10	A P X	5	-1.5	5	1.5	-3	Dip	No
					A P X	4	-1.5	4	1.5	-3	Dip	Yes
					A P X	5	-0.7	5	0.7	-1.4	Dip	Yes
1	3	8	62	10	A X	5	-1.5	5	1.5	-3	Dip	No
					A X	4.7	-1.5	4.7	1.5	-3	Dip	Yes
					A X	5	-1.45	5	1.45	-2.9	Dip	Yes
1	4	10	62	10	A P X	5	-1.5	5	1.5	-3	Dip	No
					A P X	1.2	-1.5	1.2	1.5	-3	Dip	Yes
					A P X	5	-0.65	5	0.65	-1.3	Dip	Yes
1	5	10	62	10	A X	5	-1.5	5	1.5	-3	Dip	No
					A X	4.5	-1.5	4.5	1.5	-3	Dip	Yes
					A X	5	-1.4	5	1.4	-2.8	Dip	Yes
1	6	12	62	10	A P X	5	-1.5	5	1.5	-3	Dip	No
					A P X	0	-1.5	0	1.5	-3	Dip	No
					A P X	5	-0.85	5	0.85	-1.7	Dip	Yes
1	7	12	62	10	A X	5	-1.5	5	1.5	-3	Dip	No
					A X	0	-1.5	0	1.5	-3	Dip	No
					A X	5	-0.85	5	0.85	1.8	Dip	Yes
1	8	12	62	10	P X	0	-1.5	0	1.5	-3	Dip	No
					P X	0	-0.85	0	0.85	-1.7	Dip	yes
1	9	12	62	10	X	0	-1.5	0	1.5	-3	Dip	No
					X	0	-0.85	0	0.85	-1.7	Dip	yes

Figure E 1. Empty Flat car Derailment/Extreme Exceedance Instances (Class 1)

Appendix F.
Empty Flat Car Derailment/Extreme Exceedance Instances (Class 2, 3 and 4)

Class	Derail #	Curve	MCO	Speed	Regime	L Align	L Profile	R Align	R Profile	X-level	Dip/Bump	Derail Cleared
2	10	10	62	25	A X	3	-1.125	3	1.125	-2.25	Dip	No
					A X	2.9	-1.125	2.9	1.125	-2.25	Dip	Yes
					A X	3	-1.1	3	1.1	-2.2	Dip	Yes
3	11	2	31	40	A P X	1.25	-2.25	1.25	-0.25	-2	Dip	No
					A P X	1.1	-2.25	1.1	-0.25	-2	Dip	Yes
					A P X	1.25	-2.25	1.25	-0.8	-1.45	Dip	Yes
3	12	2	31	40	A X	1.25	-1	1.25	1	-2	Dip	No
					A X	1.1	-1	1.1	1	-2	Dip	Yes
					A X	1.25	-0.6	1.25	0.6	-1.2	Dip	Yes
3	13	2	31	40	A P X	1.25	-2.25	1.25	-0.25	-2	Dip	No
					A P X	1.1	-2.25	1.1	-0.25	-2	Dip	Yes
					A P X	1.25	-1.95	1.25	0.05	-2	Dip	Yes
					A P X	1.25	-2.25	1.25	-0.8	-1.45	Dip	Yes
3	14	2	31	40	A X	1.25	-1	1.25	1	-2	Dip	No
					A X	1.1	-1	1.1	1	-2	Dip	Yes
					A X	1.25	-0.6	1.25	0.6	-1.2	Dip	Yes
3	15	6	31	40	A X	1.25	-1	1.25	1	-2	Dip	No
					A X	1.1	-1	1.1	1	-2	Dip	Yes
					A X	1.25	-0.95	1.25	0.95	-1.9	Dip	Yes
4	16	2	31	53.84	A P X	1	-2	1	-0.25	-1.75	Dip	No
					A P X	0.9	-2	0.9	-0.25	-1.75	Dip	Yes
					A P X	1	-2	1	-0.45	-1.55	Dip	Yes
					A P X	1	-1.55	1	0.2	-1.75	Dip	Yes
4	17	2	31	53.84	A X	1	-0.875	1	0.875	-1.75	Dip	No
					A X	0.9	-0.875	0.9	0.875	-1.75	Dip	Yes
					A X	1	-0.6	1	0.6	-1.2	Dip	Yes

Figure F 1. Empty Flat Car Derailment/Extreme Exceedance Instances (Class 2, 3 and 4)

Appendix G. NUCARS System Files for Simulated Vehicles

Empty Tank

System file (.SYS) for NUCARS Version 2014

==

\SYSTEM TITLE

Empty 100T Tank Car w/CCSB LT w/optional Roller Side Bearings,

Give the number of bodies, then for each, list the number, name, up to 15 characters in single quotes, and c.g. position, relative to a chosen datum, followed by the number and list of degrees of freedom required (from 1=x, 2=y, 3=z, 4=phi, 5=theta, 6=psi, 7=epsx, 8=epsy, 9=epsz), and the mass and inertias in roll, pitch, and yaw. The degrees of freedom required for each axle are 2, 3, 4, and 6. A longitudinal degree of freedom, 1, is optional.

```
 Body # ' 15 Char Name '   C.G. Posn in X, Y, & Z
           No. & DoF List   Mass, Roll, Pitch, & Yaw Inertia
------------------------------------------------------------------------
\BODY DATA
 11
! Data from FRA/ORD-81/75.2 DOT-TSC-FRA-81-16.II
! Empty weight 72932 pounds
! Loaded weight 225537 pounds
! Trucks weight 19459 pounds
! Empty
 1 'Empty Main Body'  -291.7500  0.0000  91.9
 6 1 2 3 4 5 6     138.5 377354.3 5093223.7 5089325.3
! Loaded
! 1 'LoadedMain Body'  -291.7500  0.0000  95.84
! 6 1 2 3 4 5 6     533.757 932610.7 17447176.3 17444293.3
 2 'Leading Bolster'   -35.0000  0.0000  18.0000
 6 1 2 3 4 5 6      3.7800 2.7600E+03 2.0400E+02 2.7600E+03
```

```
 3 'Trailng Bolster'  -548.5000  0.0000  18.0000
 6 1 2 3 4 5 6      3.7800 2.7600E+03 2.0400E+02 2.7600E+03
 4 'Lead Lft Sframe'   -35.0000 39.5000  18.0000
 6 1 2 3 4 5 6      2.9800 9.0000E+02 1.3700E+03 1.3700E+03
 5 'Lead Rgt Sframe'   -35.0000 -39.5000  18.0000
 6 1 2 3 4 5 6      2.9800 9.0000E+02 1.3700E+03 1.3700E+03
 6 'Trail Lt Sframe'  -548.5000 39.5000  18.0000
 6 1 2 3 4 5 6      2.9800 9.0000E+02 1.3700E+03 1.3700E+03
 7 'Trail Rt Sframe'  -548.5000 -39.5000  18.0000
 6 1 2 3 4 5 6      2.9800 9.0000E+02 1.3700E+03 1.3700E+03
 8 ' Axle number 1 '   0.0000  0.0000  18.0000
 5 1 2 3 4 6      7.7300 5.8900E+03 1.5000E+03 5.8900E+03
 9 ' Axle number 2 '   -70.0000  0.0000  18.0000
 5 1 2 3 4 6      7.7300 5.8900E+03 1.5000E+03 5.8900E+03
 10 ' Axle number 3 '  -513.5000  0.0000  18.0000
 5 1 2 3 4 6      7.7300 5.8900E+03 1.5000E+03 5.8900E+03
 11 ' Axle number 4 '  -583.5000  0.0000  18.0000
 5 1 2 3 4 6      7.7300 5.8900E+03 1.5000E+03 5.8900E+03

\CONNECTION DATA
 109
! Location of Couplers to Ground, Set to 1E1 lb/in
 1 'Coupler to Grnd' 1 1 0  36.0000 0.0000 33.0000 1 1
 2 'Coupler to Grnd' 1 1 0 -619.5000 0.0000 33.0000 1 1
! Tow Rope to Ground through C.G. location on the Car Body
 3 'Tow Rope - Grnd' 1 1 0 -291.7500 0.0000 91.9000 1 2
! ********************** LEADING TRUCK ********************************
! Lead Truck Lateral and longitudinal connections for 16" center plate using
! 6.2 line friction element for rim friction at four corners
 101 'Ld CB-Bl LgY LL' 6.2 2 1 -35.0000 8.0000 25.0625 2 1 3
 102 'Ld CB-Bl LgY LR' 6.2 1 2 -35.0000 -8.0000 25.0625 2 1 3
 103 'Ld CB-Bl LtX Fr' 6.2 2 1 -27.0000 0.0000 25.0625 1 2 3
 104 'Ld CB-Bl LtX Tr' 6.2 1 2 -43.0000 0.0000 25.0625 1 2 3
```

```
! Lead Truck Vertical and rotational connections for center plates using a
! surface friction element
 105 'Ld CB-Bl Vt/Y F' 6.5 1 2 -27.0000 0.0000 25.0625 3 1 2 4
 106 'Ld CB-Bl Vt/Y B' 6.5 1 2 -43.0000 0.0000 25.0625 3 1 2 4
 107 'Ld CB-Bl Vt/X L' 6.5 1 2 -35.0000 8.0000 25.0625 3 1 2 4
 108 'Ld CB-Bl Vt/X R' 6.5 1 2 -35.0000 -8.0000 25.0625 3 1 2 4
! Lead truck vertical centerplate dampers, gap connection
 109 'Ld CB-Bl Vt/Y F' 1.2 1 2 -27.0000 0.0000 25.0625 3 5
 110 'Ld CB-Bl Vt/Y B' 1.2 1 2 -43.0000 0.0000 25.0625 3 5
 111 'Ld CB-Bl Vt/X L' 1.2 1 2 -35.0000 8.0000 25.0625 3 5
 112 'Ld CB-Bl Vt/X R' 1.2 1 2 -35.0000 -8.0000 25.0625 3 5
! Lead Truck Vertical roller side bearing connections using a gap element
!113 'Ld Bol SB Lt Vt' 1.2 1 2 -35.0000 25.0000 29.3000 3 6
!114 'Ld Bol SB Rt Vt' 1.2 1 2 -35.0000 -25.0000 29.3000 3 6
! Lead Truck Constant Contact Side Bearings
 115 'Ld Bol SB Lt Vt' 6.2 1 2 -35.0000 -25.0000 29.3000 3 1 7
 116 'Ld Bol SB Rt Vt' 6.2 1 2 -35.0000 -25.0000 29.3000 3 1 7
! Lead truck Long.,Pitch, and Yaw bolster to side frame connections
 117 'Ld L Bol-SF LPY' 1.1 2 4 -35.0000 39.5000 18.0000 3 1 5 6 8 9 10
 118 'Ld R Bol-SF LPY' 1.1 2 5 -35.0000 -39.5000 18.0000 3 1 5 6 8 9 10
! Lead Truck Vertical bolster to side frame connections
! split into 4 seperate springs at each nest, dropped down 5"
 119 'Ld L Bol-SF V 1' 1.3 2 4 -31.2500 35.7500 14.5000 3 2 3 4 11 12 13
 120 'Ld R Bol-SF V 1' 1.3 2 5 -31.2500 -35.7500 14.5000 3 2 3 4 11 12 13
 121 'Ld L Bol-SF V 2' 1.3 2 4 -31.2500 43.2500 14.5000 3 2 3 4 11 12 13
 122 'Ld R Bol-SF V 2' 1.3 2 5 -31.2500 -43.2500 14.5000 3 2 3 4 11 12 13
 123 'Ld L Bol-SF V 3' 1.3 2 4 -38.7500 35.7500 14.5000 3 2 3 4 11 12 13
 124 'Ld R Bol-SF V 3' 1.3 2 5 -38.7500 -35.7500 14.5000 3 2 3 4 11 12 13
 125 'Ld L Bol-SF V 4' 1.3 2 4 -38.7500 43.2500 14.5000 3 2 3 4 11 12 13
 126 'Ld R Bol-SF V 4' 1.3 2 5 -38.7500 -43.2500 14.5000 3 2 3 4 11 12 13
! Lead Truck 2D Friction wedge connection between bolster and side frame
 127 'Ld Bol-SF LL Wg' 6.8 2 4 -26.5000 39.5000 18.0000 3 2 14
 128 'Ld Bol-SF LR Wg' 6.8 2 5 -26.5000 -39.5000 18.0000 3 2 14
```

129 'Ld Bol-SF TL Wg' 6.8 2 4 -43.5000 39.5000 18.0000 3 2 14
130 'Ld Bol-SF TR Wg' 6.8 2 5 -43.5000 -39.5000 18.0000 3 2 14
! Lead Truck Vertical surface friction element for side frame to axle
! connections elements are placed +/- 3.0 inches apart to react roll, and
! pitch of the side frame
131 'SdFm-Ax 1 L V L' 6.5 4 8 0.0000 42.5000 22.5000 3 1 2 15
132 'SdFm-Ax 1 L V R' 6.5 4 8 0.0000 36.5000 22.5000 3 1 2 15
133 'SdFm-Ax 1 R V R' 6.5 5 8 0.0000 -42.5000 22.5000 3 1 2 15
134 'SdFm-Ax 1 R V L' 6.5 5 8 0.0000 -36.5000 22.5000 3 1 2 15
135 'SdFm-Ax 2 L V L' 6.5 4 9 -70.0000 42.5000 22.5000 3 1 2 15
136 'SdFm-Ax 2 L V R' 6.5 4 9 -70.0000 36.5000 22.5000 3 1 2 15
137 'SdFm-Ax 2 R V R' 6.5 5 9 -70.0000 -42.5000 22.5000 3 1 2 15
138 'SdFm-Ax 2 R V L' 6.5 5 9 -70.0000 -36.5000 22.5000 3 1 2 15
! Lead Truck Vertical dampers for surface friction elements
139 'SdFm-Ax 1 L V L' 1.2 4 8 0.0000 42.5000 22.5000 3 16
140 'SdFm-Ax 1 L V R' 1.2 4 8 0.0000 36.5000 22.5000 3 16
141 'SdFm-Ax 1 R V R' 1.2 5 8 0.0000 -42.5000 22.5000 3 16
142 'SdFm-Ax 1 R V L' 1.2 5 8 0.0000 -36.5000 22.5000 3 16
143 'SdFm-Ax 2 L V L' 1.2 4 9 -70.0000 42.5000 22.5000 3 16
144 'SdFm-Ax 2 L V R' 1.2 4 9 -70.0000 36.5000 22.5000 3 16
145 'SdFm-Ax 2 R V R' 1.2 5 9 -70.0000 -42.5000 22.5000 3 16
146 'SdFm-Ax 2 R V L' 1.2 5 9 -70.0000 -36.5000 22.5000 3 16
! Lead truck side frame to axle longitudinal, lateral and yaw Stops
147 'SdFm-Ax 1 L V L' 1.1 4 8 0.0000 39.5000 22.5000 3 1 2 6 17 18 19
148 'SdFm-Ax 1 R V R' 1.1 5 8 0.0000 -39.5000 22.5000 3 1 2 6 17 18 19
149 'SdFm-Ax 2 L V L' 1.1 4 9 -70.0000 39.5000 22.5000 3 1 2 6 17 18 19
150 'SdFm-Ax 2 R V R' 1.1 5 9 -70.0000 -39.5000 22.5000 3 1 2 6 17 18 19
! Lead Truck Wheel/rail connections
151 'Ax 1 Lt Wh/Rail' 4 8 0.0000 29.7500 0.0000 1
152 'Ax 1 Rt Wh/Rail' 4 8 0.0000 -29.7500 0.0000 1
153 'Ax 2 Lt Wh/Rail' 4 9 -70.0000 29.7500 0.0000 2
154 'Ax 2 Rt Wh/Rail' 4 9 -70.0000 -29.7500 0.0000 2
155 'Dummy Ctr Plt 1' 1.1 1 2 -35.0000 0.0000 22.7000 3 4 5 6 20 20 20

```
! ********************** TRAILING TRUCK ********************************
! Trail Truck Lateral and longitudinal connections for 16" center plate using
! 6.2 line friction element for rim friction at four corners
 201 'Tr CB-Bl LgY LL' 6.2 3 1 -548.5000 8.0000 25.0625 2 1 3
 202 'Tr CB-Bl LgY LR' 6.2 1 3 -548.5000 -8.0000 25.0625 2 1 3
 203 'Tr CB-Bl LtX Fr' 6.2 3 1 -540.5000 0.0000 25.0625 1 2 3
 204 'Tr CB-Bl LtX Tr' 6.2 1 3 -556.5000 0.0000 25.0625 1 2 3
! Trail Truck Vertical and rotational connections for center plates using a
! surface friction element
 205 'Tr CB-Bl Vt/Y F' 6.5 1 3 -540.5000 0.0000 25.0625 3 1 2 4
 206 'Tr CB-Bl Vt/Y B' 6.5 1 3 -556.5000 0.0000 25.0625 3 1 2 4
 207 'Tr CB-Bl Vt/X L' 6.5 1 3 -548.5000 8.0000 25.0625 3 1 2 4
 208 'Tr CB-Bl Vt/X R' 6.5 1 3 -548.5000 -8.0000 25.0625 3 1 2 4
! Trail truck vertical centerplate dampers, gap connection
 209 'Tr CB-Bl Vt/Y F' 1.2 1 3 -540.5000 0.0000 25.0625 3 5
 210 'Tr CB-Bl Vt/Y B' 1.2 1 3 -556.5000 0.0000 25.0625 3 5
 211 'Tr CB-Bl Vt/X L' 1.2 1 3 -548.5000 8.0000 25.0625 3 5
 212 'Tr CB-Bl Vt/X R' 1.2 1 3 -548.5000 -8.0000 25.0625 3 5
! Trail Truck Vertical roller side bearing connections using a gap element
!213 'Tr Bol SB Lt Vt' 1.2 1 3 -548.5000 25.0000 29.3000 3 6
!214 'Tr Bol SB Rt Vt' 1.2 1 3 -548.5000 -25.0000 29.3000 3 6
! Trail Lead Truck Constant Contact Side Bearings
 215 'Tr Bol SB Lt Vt' 6.2 1 3 -548.5000 25.0000 29.3000 3 1 7
 216 'Tr Bol SB Rt Vt' 6.2 1 3 -548.5000 25.0000 29.3000 3 1 7
! Trail truck Long.,Pitch, and Yaw bolster to side frame connections
 217 'Tr L Bol-SF LPY' 1.1 3 6 -548.5000 39.5000 18.0000 3 1 5 6 8 9 10
 218 'Tr R Bol-SF LPY' 1.1 3 7 -548.5000 -39.5000 18.0000 3 1 5 6 8 9 10
! Trail Truck Vertical bolster to side frame connections
! split into 4 seperate springs at each nest, dropped down 5"
 219 'Tr L Bol-SF V 1' 1.3 3 6 -544.7500 35.7500 14.5000 3 2 3 4 11 12 13
 220 'Tr R Bol-SF V 1' 1.3 3 7 -544.7500 -35.7500 14.5000 3 2 3 4 11 12 13
 221 'Tr L Bol-SF V 2' 1.3 3 6 -544.7500 43.2500 14.5000 3 2 3 4 11 12 13
 222 'Tr R Bol-SF V 2' 1.3 3 7 -544.7500 -43.2500 14.5000 3 2 3 4 11 12 13
```

223 'Tr L Bol-SF V 3' 1.3 3 6 -552.2500 35.7500 14.5000 3 2 3 4 11 12 13
224 'Tr R Bol-SF V 3' 1.3 3 7 -552.2500 -35.7500 14.5000 3 2 3 4 11 12 13
225 'Tr L Bol-SF V 4' 1.3 3 6 -552.2500 43.2500 14.5000 3 2 3 4 11 12 13
226 'Tr R Bol-SF V 4' 1.3 3 7 -552.2500 -43.2500 14.5000 3 2 3 4 11 12 13
! Trail Truck 2D Friction wedge connection between bolster and side frame
227 'Tr Bol-SF LL Wg' 6.8 3 6 -540.0000 39.5000 18.0000 3 2 14
228 'Tr Bol-SF LR Wg' 6.8 3 7 -540.0000 -39.5000 18.0000 3 2 14
229 'Tr Bol-SF TL Wg' 6.8 3 6 -557.0000 39.5000 18.0000 3 2 14
230 'Tr Bol-SF TR Wg' 6.8 3 7 -557.0000 -39.5000 18.0000 3 2 14
! Trail Truck Vertical surface friction element for side frame to axle
! connections elements are placed +/- 3.0 inches apart to react roll, and
! pitch of the side frame
231 'SdFm-Ax 3 L V L' 6.5 6 10 -513.5000 42.5000 22.5000 3 1 2 15
232 'SdFm-Ax 3 L V R' 6.5 6 10 -513.5000 36.5000 22.5000 3 1 2 15
233 'SdFm-Ax 3 R V R' 6.5 7 10 -513.5000 -42.5000 22.5000 3 1 2 15
234 'SdFm-Ax 3 R V L' 6.5 7 10 -513.5000 -36.5000 22.5000 3 1 2 15
235 'SdFm-Ax 4 L V L' 6.5 6 11 -583.5000 42.5000 22.5000 3 1 2 15
236 'SdFm-Ax 4 L V R' 6.5 6 11 -583.5000 36.5000 22.5000 3 1 2 15
237 'SdFm-Ax 4 R V R' 6.5 7 11 -583.5000 -42.5000 22.5000 3 1 2 15
238 'SdFm-Ax 4 R V L' 6.5 7 11 -583.5000 -36.5000 22.5000 3 1 2 15
! Trail Truck Vertical dampers for surface friction elements
239 'SdFm-Ax 3 L V L' 1.2 6 10 -513.5000 42.5000 22.5000 3 16
240 'SdFm-Ax 3 L V R' 1.2 6 10 -513.5000 36.5000 22.5000 3 16
241 'SdFm-Ax 3 R V R' 1.2 7 10 -513.5000 -42.5000 22.5000 3 16
242 'SdFm-Ax 3 R V L' 1.2 7 10 -513.5000 -36.5000 22.5000 3 16
243 'SdFm-Ax 4 L V L' 1.2 6 11 -583.5000 42.5000 22.5000 3 16
244 'SdFm-Ax 4 L V R' 1.2 6 11 -583.5000 36.5000 22.5000 3 16
245 'SdFm-Ax 4 R V R' 1.2 7 11 -583.5000 -42.5000 22.5000 3 16
246 'SdFm-Ax 4 R V L' 1.2 7 11 -583.5000 -36.5000 22.5000 3 16
! Trail truck side frame to axle longitudinal, lateral and yaw Stops
247 'SdFm-Ax 3 L V L' 1.1 6 10 -513.5000 39.5000 22.5000 3 1 2 6 17 18 19
248 'SdFm-Ax 3 R V R' 1.1 7 10 -513.5000 -39.5000 22.5000 3 1 2 6 17 18 19
249 'SdFm-Ax 4 L V L' 1.1 6 11 -583.5000 39.5000 22.5000 3 1 2 6 17 18 19

```
 250 'SdFm-Ax 4 R V R' 1.1 7 11 -583.5000 -39.5000 22.5000 3 1 2 6 17 18 19
! Trail Truck Wheel/rail connections
 251 'Ax 3 Lt Wh/Rail' 4 10  -513.5000 29.7500 0.0000 3
 252 'Ax 3 Rt Wh/Rail' 4 10  -513.5000 -29.7500 0.0000 3
 253 'Ax 4 Lt Wh/Rail' 4 11  -583.5000 29.7500 0.0000 4
 254 'Ax 4 Rt Wh/Rail' 4 11  -583.5000 -29.7500 0.0000 4
 255 'Dummy Ctr Plt 2' 1.1 1 3 -548.5000 0.0000 22.7000 3 4 5 6 20 20 20
```

For each connection characteristic, list its number, identification numbers for the piecewise linear stiffness and damping characteristics, respectively, zero if absent, and the force, moment, or stroke limits in extn and compn, (if no limit exists, set the values outside the expected range).

```
 Pair # Stiffness & Damping F/S-extn. F/S-comp. K/D-parameters
--------------------------------------------------------------------------
\CHARACTERISTIC DATA
! ************************ Couplers **********************************
 1  1 0 1.00E+09 -1.00E+09
! Tow Rope
 2  2 3 1.00E+09 -1.00E+09
! ********************* Center Plate ********************************
! Center plate longitudinal and lateral rim friction
 3  4 0 1.00E+00 -1.00E+00 0.00E+00 1.00E+06 1.00E+03 5.00E-01
! Centerplate vertical with longitudinal and lateral surface friction
!
! Cw = Car weight
! Mu1 friction value for the center plate
! Mu2 effective friction value for this simulation
! R= radius of center plate
!
! Charct. #5 The normal formula for calculating the center plate breakout
! torque for one bowl is (Cw*Mu1*R)/3. This model assumes all loads are
! carried at the lateral edges of the center plate. This produces a breakout
```

```
! torque equal to (Mu2*Cw*R)/4 for each edge. Setting the two equations
! equal to each other produces the effective Mu, R relationship. Therefore,
! Mu1*2/3 = Mu2.
! Center Plate Lube 0.1 2/3*.1 = 0.0666
! Center Plate Lube 0.2 2/3*.2 = 0.1333
! Center Plate Lube 0.3 2/3*.3 = 0.2000
! Center Plate Lube 0.4 2/3*.4 = 0.2666
! Center Plate Lube 0.5 2/3*.5 = 0.3333
! 4 5   0  1.0E06 1.0E03 0.0666
! 4 5   0  1.0E06 1.0E03 0.3333
 4  5 0        1.00E+06 1.00E+03 2.67E-01
! Centerplate damping, type 1.2 connection
 5  0 6 1.00E+03 3.04E-03
!
! ********************** Roller Side Bearings ********************************
! Gap element at for roller side bearings, -0.250 accounts for deflection of
! center plate springs.
! 6  7 8 1.00E+03 -2.50E-01
! ********************** Constant Contact Side Bearings **********************
 7 9   10  3.0  -3.0  0.0  1.0E06 1.0E03 0.3
! ********************** Bolster to Side Frame Connections *******************
! Longitudinal
 8 11 12 1.00E+09 -1.00E+09
! Pitch stiffness and stops
 9 13 0 1.00E+09 -1.00E+09
! Warp/torsion
 10 14 0 1.00E+09 -1.00E+09
! Lateral stiffness and stops
 11 15 0 1.00E+09 -1.00E+09
! Vertical Springs
 12 16 0 0.00E+00 -1.00E+09
! Dummy roll characteristic for type 1.3 connection
 13  0 0 1.00E+09 -1.00E+09
```

```
! # 4 is a 6.3 wedge element with pwl numbers, wedge angle, force, LVB,
! and friction, Constant damped truck is 1979 lb/in in the control coils
! at zero wedge rise the control coils are compressed 1.8393 inches
! 0.0 inch wedge rise
! Ch # Pwl Stiff Pwl Damp Wedge Angle Force LB  Mu
! 14  0   0  37.5  3.640E03 1.0E04 0.40
! 0.25 inch wedge rise (1.8393 - 0.25 = 1.5893 * 1979 = 3145)
! Ch # Pwl Stiff Pwl Damp Wedge Angle Force LB  Mu
! 14  0   0  37.5  3.1450E03 1.0E04 0.40
! 0.375 inch wedge rise (1.8393 -.375=1.4643*1979=2898)
! Ch # Pwl Stiff Pwl Damp Wedge Angle Force LB  Mu
! 14  0   0  37.5  2.898E03 1.0E04 0.40
! modified for new type 6.7, MU1 for slope Mu2 for Face, T=Toe out, F=Toe in
! Ch # Pwl Stf Pwl Damp Wedge Ang Force LB  Mu1 Mu2 Toe
! 14  0 0 3.75E+01 2.90E+03 1.00E+04 4.00E-01 4.00E-01 .T.
! 0.50 inch wedge rise (1.8393 - 0.50 = 1.3393 * 1979 = 2650)
! Ch # Pwl Stiff Pwl Damp Wedge Angle Force LB  Mu
! 14  0   0  37.5  2.650E03 1.0E04 0.40
! 0.75 inch wedge rise (1.8393 - 0.75 = 1.0893 * 1979 = 2155)
! Ch # Pwl Stiff Pwl Damp Wedge Angle Force LB  Mu
! 14  0   0  37.5  2.155E03 1.0E04 0.40
! Option for a VARIABLE DAMPED TRUCK design
! Ch # Pwl Stf Pwl Damp Wedge Ang Force LB  Mu1 Mu2 Toe
! 14  17   0  32.0  0.0 1.0E04 0.40 0.40 .T.
! 6.8 Wedge
! Ch # Pwl Stiff PwlDamp Wedge Angle Force  C1  C2  Mu Face Mu Back Toe Long K
 14 17   0  35.0  0.0 1.0E6 1.0E3 0.32  0.32 .T. 1.0E5
!
!****************** Bearing Adapter Side Frame to Axle ********************
! Vertical side frame to axle connections with friction, type 6.5
 15 18 0        1.00E+06 1.00E+03 5.00E-01
! Vertical damping for bearing adapters with gap element
 16  0 19 1.00E+03 3.14E-02
```

```
! Longitudinal stiffness and stops
 17 20 0 1.00E+09 -1.00E+09
! Lateral stiffness and stops
 18 21 0 1.00E+09 -1.00E+09
! Yaw stiffness and stops
 19 22 0 1.00E+09 -1.00E+09
! Dummy Center Plate Roll/Pitch/Yaw Connection
 20  0 0 1.00E+09 -1.00E+09
```

For type 4 - axle to track characteristics, give a lateral stiffness and damping and identification numbers for the vertical PWL stiffness and damping, then for each, list an identification number, the nominal wheel radius, WRAD, a wheel rotation index, INDWH, .F. for solid, .T. for independent wheels, traction torque input nos., ITRQ, for left and right wheels, 0 for none, and, for independent wheels, KWHL, DWHL, the axle torsional stiffness and damping.

```
 Axle #  WRAD  INDWH  ITRQ-L ITRQ-R  KWHL  DWHL
-------------------------------------------------------------------------
$\WHEEL/RAIL ELEMENT TIE
$ 1.000E+05 1.000E+02 1.000E+05 1.000E+02 2.500E+05 2.500E+02
\WHEEL/RAIL ELEMENT
 1.E5 1.E2 2.5E5 2.5E2
 1  18.000  .F.   0   0
 2  18.000  .F.   0   0
 3  18.000  .F.   0   0
 4  18.000  .F.   0   0
```

For each piecewise linear function, list the identification number, the number of break points, and the ordinate, lb or in-lb, over abscissa, inches or rad, at each break point.

Note - extension is assumed to be positive for both ordinate and abscissa and
  0.0 for the first break point indicates symmetry about the origin.

```
 PWL IBP Ordinates over Abscissae
------------------------------------------------------------------------
\PWL DATA
! ************************ Couplers **********************************
! Coupler to Ground Lead and Trail Ends
 1 2 0.0000E+00 1.0000E+01
   0.000000 1.000000
! Tow Rope to Ground Through C.G.
! 1500 LB/IN
 2 2 0.0000E+00 1.5000E+03
   0.000000 1.000000
 3 2 0.0000E+00 1.5000E+02
   0.000000 1.000000
! ********************* Center plate Connections ***************************
! Longitudinal and lateral rim normal stiffness
! Steel on steel, with 80 lb/in +/-0.125 inch gap
 4 4 -1.1010E+03 -1.0000E+01 0.0000E+00 0.0000E+00
   -0.126000 -0.125000 0.000000 1.000000
! Vertical lift off spring for center plate
! The center plate stiffness has been increased from 1xE6 to 1xE7 to
! improve the roll calculation.
! with initial offsets
!Empty
 5 3 -4.4340E+03 0.0000E+00 0.0000E+00
   0.000000 0.0004434 1.000000
! Loaded
! 5 3 -2.5509E+04 0.0000E+00 0.0000E+00
!   0.000000 0.002351 1.000000
! Damping of center plate
 6 2 0.0000E+00 1.0000E+03
   0.000000 1.000000
! ********************* Roller Side Bearings ******************************
```

```
! Lift off spring for side bearings
! 7 3 -1.0000E+06 0.0000E+00 0.0000E+00
!   -1.000000 0.000000 1.000000
! Damping of side bearings
! 8 2 0.0000E+00 0.0000E+00
!   0.000000 1.000000
! ********************* Constant Contact Side Bearings *********************
! TCC-III-45 Long Travels
 9 7 -8.8000E+03 -7.8000E+03 -5.8000E+03 -4.3000E+03 -1.8000E+03 0.0000E+00
0.0000E+00
   -0.626000 -0.625000 -0.312500 0.000000 0.500000 1.000000 2.000000
! CCSB Damping
 10 3 0.0000E+00 1.0000E+03 1.0000E+03
   0.000000 0.050000 1.000000
! ********************* Bolster to Side Frame Connections *******************
! Longitudinal
 11 2 0.0000E+00 1.0000E+06
   0.000000 1.000000
 12 2 0.0000E+00 1.0000E+03
   0.000000 1.000000
! Pitch Stiffness and Stops Mid Tolerance is Approx +/- 2.4 Degrees=0.042mRad
 13 3 0.0000E+00 0.0000E+00 6.4000E+07
   0.000000 0.042000 1.042000
! ****************** Warp resistance ************************************
! worn truck
! Warp resistance for bolster to side frame
! 14  3  0.0  5.25E04 6.924E05
!     0.0  0.030  0.040
! New truck
! Warp resistance for bolster to side frame
 14 3 0.0000E+00 2.5500E+05 8.9500E+05
   0.000000 0.030000 0.040000
! Stiff H-frame truck
```

! Warp resistance for bolster to side frame

! 14 3 0.0 1.275E06 1.915E06

!   0.0 0.030 0.040

! ******************************** Loaded ******************************

! LATERAL STIFFNESS OF BOLSTER TO SIDE FRAME CONNECTION FOR ONE OF 4 EFFECTIVE SPRINGS in pounds and inches

! 7-D5 OUTER 6-D5 INNER SPRINGS I INNER CONTROL COILS, 2-B432 O OUTER CONTROL 2-B433 I INNER CONTROL COILS

! 15 3 0.000E+0 1.756E+3 1.018E+5

!   0.0000 0.5000 0.6000

! VERTICAL SUSPENSION WITH STATIC DEFLECTIONS FOR 4 EQUIVALENT SPRINGS

! 7-D5 OUTER 6-D5 INNER SPRINGS

! IN LBS AND INCHES

! 16 6 -4.577E+4 -2.077E+4 -1.102E+4 -1.050E+2 0.000E+0 0.000E+0

!   -1.8396 -1.7396 0.0000 1.9479 2.0104 3.7604

! FRICTION WEDGE CONTROL SPRING STIFFNESS FOR EQUIVALENT SPRINGS

! 2-B432 O OUTER CONTROL 2-B433 I INNER CONTROL COILS

! 17 7 -5.668E+4 -6.681E+3 -4.087E+3 -1.183E+3 -1.090E+3 -6.444E+1 0.000E+0

!   -1.8396 -1.7396 0.0000 1.9479 2.0104 2.6979 3.7604

! ******************************** Empty ****************************

! LATERAL STIFFNESS OF BOLSTER TO SIDE FRAME CONNECTION FOR ONE OF 4 EFFECTIVE SPRINGS in pounds and inches

! 7-D5 OUTER 6-D5 INNER SPRINGS I INNER CONTROL COILS, 2-B432 O OUTER CONTROL 2-B433 I INNER CONTROL COILS

15 3 0.000E+0 1.356E+3 1.014E+5

0.0000 0.5000 0.6000

! VERTICAL SUSPENSION WITH STATIC DEFLECTIONS FOR 4 EQUIVALENT SPRINGS

! 7-D5 OUTER 6-D5 INNER SPRINGS I INNER CONTROL COILS

! IN LBS AND INCHES

16 6 -4.577E+4 -2.077E+4 -2.601E+3 -1.050E+2 0.000E+0 0.000E+0

-3.3419 -3.2419 0.0000 0.4456 0.5081 2.2581

! FRICTION WEDGE CONTROL SPRING STIFFNESS FOR EQUIVALENT SPRINGS

```
! 2-B432 O OUTER CONTROL 2-B433 I INNER CONTROL COILS
 17 7 -5.668E+4 -6.681E+3 -1.847E+3 -1.183E+3 -1.090E+3 -6.444E+1 0.000E+0
   -3.3419 -3.2419 0.0000 0.4456 0.5081 1.1956 2.2581
!****************** Bearing Adapter Side Frame to Axle ********************
! Vertical Bearing adapter connection with offset for static load
!
!Empty
 18 3 -3.8121E+03 0.0000E+00 0.0000E+00
   0.000000 0.003812 1.000000
! Loaded
! 18 3 -1.3350E+04 0.0000E+00 0.0000E+00
!   0.000000 0.013350 1.000000
! Vertical Bearing adapter damping
 19 2 0.0000E+00 1.0000E+03
   0.000000 1.000000
! Bearing adapter stops
! Longitudinal Stiffness with Stops
 20 3 0.0000E+00 1.0000E+00 1.0000E+03
   0.000000 0.046800 0.047800
! Lateral Stiffness with Stops
 21 3 0.0000E+00 1.0000E+00 1.0000E+03
   0.000000 0.250000 0.251000
! Yaw Stiffness with Stops
 22 3 0.0000E+00 0.0000E+00 6.4000E+05
   0.000000 0.030000 0.040000
```

Loaded Tank

System file (.SYS) for NUCARS Version 2014

==

\SYSTEM TITLE

Loaded 100T Tank Car w/CCSB LT w/optional Roller Side Bearings,

Give the number of bodies, then for each, list the number, name, up to 15 characters in single quotes, and c.g. position, relative to a chosen datum, followed by the number and list of degrees of freedom required (from 1=x, 2=y, 3=z, 4=phi, 5=theta, 6=psi, 7=epsx, 8=epsy, 9=epsz), and the mass and inertias in roll, pitch, and yaw. The degrees of freedom required for each axle are 2, 3, 4, and 6. A longitudinal degree of freedom, 1, is optional.

```
 Body # ' 15 Char Name '   C.G. Posn in X, Y, & Z
            No. & DoF List   Mass, Roll, Pitch, & Yaw Inertia
------------------------------------------------------------------------
\BODY DATA
 11
! Data from FRA/ORD-81/75.2 DOT-TSC-FRA-81-16.II
! Empty weight 72932 pounds
! Loaded weight 225537 pounds
! Trucks weight 19459 pounds
! Empty
! 1 'Empty Main Body'  -291.7500  0.0000  91.9
! 6 1 2 3 4 5 6     138.5 377354.3 5093223.7 5089325.3
! Loaded
 1 'LoadedMain Body'  -291.7500  0.0000  95.84
 6 1 2 3 4 5 6     533.757 932610.7 17447176.3 17444293.3
 2 'Leading Bolster'   -35.0000  0.0000  16.5000
 6 1 2 3 4 5 6      3.7800 2.7600E+03 2.0400E+02 2.7600E+03
 3 'Trailng Bolster'  -548.5000  0.0000  16.5000
 6 1 2 3 4 5 6      3.7800 2.7600E+03 2.0400E+02 2.7600E+03
 4 'Lead Lft Sframe'   -35.0000 39.5000  18.0000
 6 1 2 3 4 5 6      2.9800 9.0000E+02 1.3700E+03 1.3700E+03
```

```
 5 'Lead Rgt Sframe'   -35.0000 -39.5000  18.0000
 6 1 2 3 4 5 6      2.9800 9.0000E+02 1.3700E+03 1.3700E+03
 6 'Trail Lt Sframe'  -548.5000 39.5000  18.0000
 6 1 2 3 4 5 6      2.9800 9.0000E+02 1.3700E+03 1.3700E+03
 7 'Trail Rt Sframe'  -548.5000 -39.5000  18.0000
 6 1 2 3 4 5 6      2.9800 9.0000E+02 1.3700E+03 1.3700E+03
 8 ' Axle number 1 '   0.0000  0.0000  18.0000
 5 1 2 3 4 6      7.7300 5.8900E+03 1.5000E+03 5.8900E+03
 9 ' Axle number 2 '   -70.0000  0.0000  18.0000
 5 1 2 3 4 6      7.7300 5.8900E+03 1.5000E+03 5.8900E+03
 10 ' Axle number 3 '  -513.5000  0.0000  18.0000
 5 1 2 3 4 6      7.7300 5.8900E+03 1.5000E+03 5.8900E+03
 11 ' Axle number 4 '  -583.5000  0.0000  18.0000
 5 1 2 3 4 6      7.7300 5.8900E+03 1.5000E+03 5.8900E+03

\CONNECTION DATA
 109
! Location of Couplers to Ground, Set to 1E1 lb/in
 1 'Coupler to Grnd' 1 1 0  36.0000 0.0000 31.5000 1 1
 2 'Coupler to Grnd' 1 1 0 -619.5000 0.0000 31.5000 1 1
! Tow Rope to Ground through C.G. location on the Car Body
 3 'Tow Rope - Grnd' 1 1 0 -291.7500 0.0000 95.8400 1 2
! ********************** LEADING TRUCK ********************************
! Lead Truck Lateral and longitudinal connections for 16" center plate using
! 6.2 line friction element for rim friction at four corners
 101 'Ld CB-Bl LgY LL' 6.2 2 1 -35.0000 8.0000 22.7000 2 1 3
 102 'Ld CB-Bl LgY LR' 6.2 1 2 -35.0000 -8.0000 22.7000 2 1 3
 103 'Ld CB-Bl LtX Fr' 6.2 2 1 -27.0000 0.0000 22.7000 1 2 3
 104 'Ld CB-Bl LtX Tr' 6.2 1 2 -43.0000 0.0000 22.7000 1 2 3
! Lead Truck Vertical and rotational connections for center plates using a
! surface friction element
 105 'Ld CB-Bl Vt/Y F' 6.5 1 2 -27.0000 0.0000 22.7000 3 1 2 4
 106 'Ld CB-Bl Vt/Y B' 6.5 1 2 -43.0000 0.0000 22.7000 3 1 2 4
```

107 'Ld CB-Bl Vt/X L' 6.5 1 2 -35.0000 8.0000 22.7000 3 1 2 4

108 'Ld CB-Bl Vt/X R' 6.5 1 2 -35.0000 -8.0000 22.7000 3 1 2 4

! Lead truck vertical centerplate dampers, gap connection

109 'Ld CB-Bl Vt/Y F' 1.2 1 2 -27.0000 0.0000 22.7000 3 5

110 'Ld CB-Bl Vt/Y B' 1.2 1 2 -43.0000 0.0000 22.7000 3 5

111 'Ld CB-Bl Vt/X L' 1.2 1 2 -35.0000 8.0000 22.7000 3 5

112 'Ld CB-Bl Vt/X R' 1.2 1 2 -35.0000 -8.0000 22.7000 3 5

! Lead Truck Vertical roller side bearing connections using a gap element

!113 'Ld Bol SB Lt Vt' 1.2 1 2 -35.0000 25.0000 27.8000 3 6

!114 'Ld Bol SB Rt Vt' 1.2 1 2 -35.0000 -25.0000 27.8000 3 6

! Lead Truck Constant Contact Side Bearings

115 'Ld Bol SB Lt Vt' 6.2 1 2 -35.0000 -25.0000 27.8000 3 1 7

116 'Ld Bol SB Rt Vt' 6.2 1 2 -35.0000 -25.0000 27.8000 3 1 7

! Lead truck Long.,Pitch, and Yaw bolster to side frame connections

117 'Ld L Bol-SF LPY' 1.1 2 4 -35.0000 39.5000 16.5000 3 1 5 6 8 9 10

118 'Ld R Bol-SF LPY' 1.1 2 5 -35.0000 -39.5000 16.5000 3 1 5 6 8 9 10

! Lead Truck Vertical bolster to side frame connections

! split into 4 seperate springs at each nest, dropped down 5"

119 'Ld L Bol-SF V 1' 1.3 2 4 -31.2500 35.7500 13.0000 3 2 3 4 11 12 13

120 'Ld R Bol-SF V 1' 1.3 2 5 -31.2500 -35.7500 13.0000 3 2 3 4 11 12 13

121 'Ld L Bol-SF V 2' 1.3 2 4 -31.2500 43.2500 13.0000 3 2 3 4 11 12 13

122 'Ld R Bol-SF V 2' 1.3 2 5 -31.2500 -43.2500 13.0000 3 2 3 4 11 12 13

123 'Ld L Bol-SF V 3' 1.3 2 4 -38.7500 35.7500 13.0000 3 2 3 4 11 12 13

124 'Ld R Bol-SF V 3' 1.3 2 5 -38.7500 -35.7500 13.0000 3 2 3 4 11 12 13

125 'Ld L Bol-SF V 4' 1.3 2 4 -38.7500 43.2500 13.0000 3 2 3 4 11 12 13

126 'Ld R Bol-SF V 4' 1.3 2 5 -38.7500 -43.2500 13.0000 3 2 3 4 11 12 13

! Lead Truck 2D Friction wedge connection between bolster and side frame

127 'Ld Bol-SF LL Wg' 6.8 2 4 -26.5000 39.5000 16.5000 3 2 14

128 'Ld Bol-SF LR Wg' 6.8 2 5 -26.5000 -39.5000 16.5000 3 2 14

129 'Ld Bol-SF TL Wg' 6.8 2 4 -43.5000 39.5000 16.5000 3 2 14

130 'Ld Bol-SF TR Wg' 6.8 2 5 -43.5000 -39.5000 16.5000 3 2 14

! Lead Truck Vertical surface friction element for side frame to axle

! connections elements are placed +/- 3.0 inches apart to react roll, and

```
! pitch of the side frame
 131 'SdFm-Ax 1 L V L' 6.5 4 8  0.0000 42.5000 22.5000 3 1 2 15
 132 'SdFm-Ax 1 L V R' 6.5 4 8  0.0000 36.5000 22.5000 3 1 2 15
 133 'SdFm-Ax 1 R V R' 6.5 5 8  0.0000 -42.5000 22.5000 3 1 2 15
 134 'SdFm-Ax 1 R V L' 6.5 5 8  0.0000 -36.5000 22.5000 3 1 2 15
 135 'SdFm-Ax 2 L V L' 6.5 4 9 -70.0000 42.5000 22.5000 3 1 2 15
 136 'SdFm-Ax 2 L V R' 6.5 4 9 -70.0000 36.5000 22.5000 3 1 2 15
 137 'SdFm-Ax 2 R V R' 6.5 5 9 -70.0000 -42.5000 22.5000 3 1 2 15
 138 'SdFm-Ax 2 R V L' 6.5 5 9 -70.0000 -36.5000 22.5000 3 1 2 15
! Lead Truck Vertical dampers for surface friction elements
 139 'SdFm-Ax 1 L V L' 1.2 4 8  0.0000 42.5000 22.5000 3 16
 140 'SdFm-Ax 1 L V R' 1.2 4 8  0.0000 36.5000 22.5000 3 16
 141 'SdFm-Ax 1 R V R' 1.2 5 8  0.0000 -42.5000 22.5000 3 16
 142 'SdFm-Ax 1 R V L' 1.2 5 8  0.0000 -36.5000 22.5000 3 16
 143 'SdFm-Ax 2 L V L' 1.2 4 9 -70.0000 42.5000 22.5000 3 16
 144 'SdFm-Ax 2 L V R' 1.2 4 9 -70.0000 36.5000 22.5000 3 16
 145 'SdFm-Ax 2 R V R' 1.2 5 9 -70.0000 -42.5000 22.5000 3 16
 146 'SdFm-Ax 2 R V L' 1.2 5 9 -70.0000 -36.5000 22.5000 3 16
! Lead truck side frame to axle longitudinal, lateral and yaw Stops
 147 'SdFm-Ax 1 L V L' 1.1 4 8  0.0000 39.5000 22.5000 3 1 2 6 17 18 19
 148 'SdFm-Ax 1 R V R' 1.1 5 8  0.0000 -39.5000 22.5000 3 1 2 6 17 18 19
 149 'SdFm-Ax 2 L V L' 1.1 4 9 -70.0000 39.5000 22.5000 3 1 2 6 17 18 19
 150 'SdFm-Ax 2 R V R' 1.1 5 9 -70.0000 -39.5000 22.5000 3 1 2 6 17 18 19
! Lead Truck Wheel/rail connections
 151 'Ax 1 Lt Wh/Rail' 4 8   0.0000 29.7500 0.0000 1
 152 'Ax 1 Rt Wh/Rail' 4 8   0.0000 -29.7500 0.0000 1
 153 'Ax 2 Lt Wh/Rail' 4 9  -70.0000 29.7500 0.0000 2
 154 'Ax 2 Rt Wh/Rail' 4 9  -70.0000 -29.7500 0.0000 2
 155 'Dummy Ctr Plt 1' 1.1 1 2 -35.0000 0.0000 22.7000 3 4 5 6 20 20 20
! ********************* TRAILING TRUCK ******************************
! Trail Truck Lateral and longitudinal connections for 16" center plate using
! 6.2 line friction element for rim friction at four corners
 201 'Tr CB-Bl LgY LL' 6.2 3 1 -548.5000 8.0000 22.7000 2 1 3
```

```
 202 'Tr CB-Bl LgY LR' 6.2 1 3 -548.5000 -8.0000 22.7000 2 1 3
 203 'Tr CB-Bl LtX Fr' 6.2 3 1 -540.5000 0.0000 22.7000 1 2 3
 204 'Tr CB-Bl LtX Tr' 6.2 1 3 -556.5000 0.0000 22.7000 1 2 3
! Trail Truck Vertical and rotational connections for center plates using a
! surface friction element
 205 'Tr CB-Bl Vt/Y F' 6.5 1 3 -540.5000 0.0000 22.7000 3 1 2 4
 206 'Tr CB-Bl Vt/Y B' 6.5 1 3 -556.5000 0.0000 22.7000 3 1 2 4
 207 'Tr CB-Bl Vt/X L' 6.5 1 3 -548.5000 8.0000 22.7000 3 1 2 4
 208 'Tr CB-Bl Vt/X R' 6.5 1 3 -548.5000 -8.0000 22.7000 3 1 2 4
! Trail truck vertical centerplate dampers, gap connection
 209 'Tr CB-Bl Vt/Y F' 1.2 1 3 -540.5000 0.0000 22.7000 3 5
 210 'Tr CB-Bl Vt/Y B' 1.2 1 3 -556.5000 0.0000 22.7000 3 5
 211 'Tr CB-Bl Vt/X L' 1.2 1 3 -548.5000 8.0000 22.7000 3 5
 212 'Tr CB-Bl Vt/X R' 1.2 1 3 -548.5000 -8.0000 22.7000 3 5
! Trail Truck Vertical roller side bearing connections using a gap element
!213 'Tr Bol SB Lt Vt' 1.2 1 3 -548.5000 25.0000 27.8000 3 6
!214 'Tr Bol SB Rt Vt' 1.2 1 3 -548.5000 -25.0000 27.8000 3 6
! Trail Lead Truck Constant Contact Side Bearings
 215 'Tr Bol SB Lt Vt' 6.2 1 3 -548.5000 25.0000 27.8000 3 1 7
 216 'Tr Bol SB Rt Vt' 6.2 1 3 -548.5000 25.0000 27.8000 3 1 7
! Trail truck Long.,Pitch, and Yaw bolster to side frame connections
 217 'Tr L Bol-SF LPY' 1.1 3 6 -548.5000 39.5000 16.5000 3 1 5 6 8 9 10
 218 'Tr R Bol-SF LPY' 1.1 3 7 -548.5000 -39.5000 16.5000 3 1 5 6 8 9 10
! Trail Truck Vertical bolster to side frame connections
! split into 4 seperate springs at each nest, dropped down 5"
 219 'Tr L Bol-SF V 1' 1.3 3 6 -544.7500 35.7500 13.0000 3 2 3 4 11 12 13
 220 'Tr R Bol-SF V 1' 1.3 3 7 -544.7500 -35.7500 13.0000 3 2 3 4 11 12 13
 221 'Tr L Bol-SF V 2' 1.3 3 6 -544.7500 43.2500 13.0000 3 2 3 4 11 12 13
 222 'Tr R Bol-SF V 2' 1.3 3 7 -544.7500 -43.2500 13.0000 3 2 3 4 11 12 13
 223 'Tr L Bol-SF V 3' 1.3 3 6 -552.2500 35.7500 13.0000 3 2 3 4 11 12 13
 224 'Tr R Bol-SF V 3' 1.3 3 7 -552.2500 -35.7500 13.0000 3 2 3 4 11 12 13
 225 'Tr L Bol-SF V 4' 1.3 3 6 -552.2500 43.2500 13.0000 3 2 3 4 11 12 13
 226 'Tr R Bol-SF V 4' 1.3 3 7 -552.2500 -43.2500 13.0000 3 2 3 4 11 12 13
```

```
! Trail Truck 2D Friction wedge connection between bolster and side frame
 227 'Tr Bol-SF LL Wg' 6.8 3 6 -540.0000 39.5000 16.5000 3 2 14
 228 'Tr Bol-SF LR Wg' 6.8 3 7 -540.0000 -39.5000 16.5000 3 2 14
 229 'Tr Bol-SF TL Wg' 6.8 3 6 -557.0000 39.5000 16.5000 3 2 14
 230 'Tr Bol-SF TR Wg' 6.8 3 7 -557.0000 -39.5000 16.5000 3 2 14
! Trail Truck Vertical surface friction element for side frame to axle
! connections elements are placed +/- 3.0 inches apart to react roll, and
! pitch of the side frame
 231 'SdFm-Ax 3 L V L' 6.5 6 10 -513.5000 42.5000 22.5000 3 1 2 15
 232 'SdFm-Ax 3 L V R' 6.5 6 10 -513.5000 36.5000 22.5000 3 1 2 15
 233 'SdFm-Ax 3 R V R' 6.5 7 10 -513.5000 -42.5000 22.5000 3 1 2 15
 234 'SdFm-Ax 3 R V L' 6.5 7 10 -513.5000 -36.5000 22.5000 3 1 2 15
 235 'SdFm-Ax 4 L V L' 6.5 6 11 -583.5000 42.5000 22.5000 3 1 2 15
 236 'SdFm-Ax 4 L V R' 6.5 6 11 -583.5000 36.5000 22.5000 3 1 2 15
 237 'SdFm-Ax 4 R V R' 6.5 7 11 -583.5000 -42.5000 22.5000 3 1 2 15
 238 'SdFm-Ax 4 R V L' 6.5 7 11 -583.5000 -36.5000 22.5000 3 1 2 15
! Trail Truck Vertical dampers for surface friction elements
 239 'SdFm-Ax 3 L V L' 1.2 6 10 -513.5000 42.5000 22.5000 3 16
 240 'SdFm-Ax 3 L V R' 1.2 6 10 -513.5000 36.5000 22.5000 3 16
 241 'SdFm-Ax 3 R V R' 1.2 7 10 -513.5000 -42.5000 22.5000 3 16
 242 'SdFm-Ax 3 R V L' 1.2 7 10 -513.5000 -36.5000 22.5000 3 16
 243 'SdFm-Ax 4 L V L' 1.2 6 11 -583.5000 42.5000 22.5000 3 16
 244 'SdFm-Ax 4 L V R' 1.2 6 11 -583.5000 36.5000 22.5000 3 16
 245 'SdFm-Ax 4 R V R' 1.2 7 11 -583.5000 -42.5000 22.5000 3 16
 246 'SdFm-Ax 4 R V L' 1.2 7 11 -583.5000 -36.5000 22.5000 3 16
! Trail truck side frame to axle longitudinal, lateral and yaw Stops
 247 'SdFm-Ax 3 L V L' 1.1 6 10 -513.5000 39.5000 22.5000 3 1 2 6 17 18 19
 248 'SdFm-Ax 3 R V R' 1.1 7 10 -513.5000 -39.5000 22.5000 3 1 2 6 17 18 19
 249 'SdFm-Ax 4 L V L' 1.1 6 11 -583.5000 39.5000 22.5000 3 1 2 6 17 18 19
 250 'SdFm-Ax 4 R V R' 1.1 7 11 -583.5000 -39.5000 22.5000 3 1 2 6 17 18 19
! Trail Truck Wheel/rail connections
 251 'Ax 3 Lt Wh/Rail' 4 10  -513.5000 29.7500 0.0000 3
 252 'Ax 3 Rt Wh/Rail' 4 10  -513.5000 -29.7500 0.0000 3
```

```
 253 'Ax 4 Lt Wh/Rail' 4 11  -583.5000 29.7500 0.0000 4
 254 'Ax 4 Rt Wh/Rail' 4 11  -583.5000 -29.7500 0.0000 4
 255 'Dummy Ctr Plt 2' 1.1 1 3 -548.5000 0.0000 22.7000 3 4 5 6 20 20 20
```

For each connection characteristic, list its number, identification numbers for the piecewise linear stiffness and damping characteristics, respectively, zero if absent, and the force, moment, or stroke limits in extn and compn, (if no limit exists, set the values outside the expected range).

```
 Pair # Stiffness & Damping F/S-extn. F/S-comp. K/D-parameters
-------------------------------------------------------------------------
\CHARACTERISTIC DATA
! ************************* Couplers ***********************************
 1  1 0 1.00E+09 -1.00E+09
! Tow Rope
 2  2 3 1.00E+09 -1.00E+09
! ********************* Center Plate ***********************************
! Center plate longitudinal and lateral rim friction
 3  4 0 1.00E+00 -1.00E+00 0.00E+00 1.00E+06 1.00E+03 5.00E-01
! Centerplate vertical with longitudinal and lateral surface friction
!
! Cw = Car weight
! Mu1 friction value for the center plate
! Mu2 effective friction value for this simulation
! R= radius of center plate
!
! Charct. #5 The normal formula for calculating the center plate breakout
! torque for one bowl is (Cw*Mu1*R)/3. This model assumes all loads are
! carried at the lateral edges of the center plate. This produces a breakout
! torque equal to (Mu2*Cw*R)/4 for each edge. Setting the two equations
! equal to each other produces the effective Mu, R relationship. Therefore,
! Mu1*2/3 = Mu2.
! Center Plate Lube 0.1 2/3*.1 = 0.0666
```

```
! Center Plate Lube 0.2 2/3*.2 = 0.1333
! Center Plate Lube 0.3 2/3*.3 = 0.2000
! Center Plate Lube 0.4 2/3*.4 = 0.2666
! Center Plate Lube 0.5 2/3*.5 = 0.3333
! 4 5   0  1.0E06 1.0E03 0.0666
! 4 5   0  1.0E06 1.0E03 0.3333
 4  5 0       1.00E+06 1.00E+03 2.67E-01
! Centerplate damping, type 1.2 connection
 5  0 6 1.00E+03 3.04E-03
! ********************* Roller Side Bearings ******************************
! Gap element at for roller side bearings, -0.250 accounts for deflection of
! center plate springs.
! 6  7 8 1.00E+03 -2.50E-01
! ********************* Constant Contact Side Bearings *********************
 7 9   10  3.0  -3.0  0.0  1.0E06 1.0E03 0.3
! ********************* Bolster to Side Frame Connections ******************
! Longitudinal
 8 11 12 1.00E+09 -1.00E+09
! Pitch stiffness and stops
 9 13 0 1.00E+09 -1.00E+09
! Warp/torsion
 10 14 0 1.00E+09 -1.00E+09
! Lateral stiffness and stops
 11 15 0 1.00E+09 -1.00E+09
! Vertical Springs
 12 16 0 0.00E+00 -1.00E+09
! Dummy roll characteristic for type 1.3 connection
 13  0 0 1.00E+09 -1.00E+09
! # 4 is a 6.3 wedge element with pwl numbers, wedge angle, force, LVB,
! and friction, Constant damped truck is 1979 lb/in in the control coils
! at zero wedge rise the control coils are compressed 1.8393 inches
! 0.0 inch wedge rise
! Ch # Pwl Stiff Pwl Damp Wedge Angle Force LB  Mu
```

```
! 14  0   0  37.5  3.640E03 1.0E04 0.40
! 0.25 inch wedge rise (1.8393 - 0.25 = 1.5893 * 1979 = 3145)
! Ch # Pwl Stiff Pwl Damp Wedge Angle Force LB  Mu
! 14  0   0  37.5  3.1450E03 1.0E04 0.40
! 0.375 inch wedge rise (1.8393 -.375=1.4643*1979=2898)
! Ch # Pwl Stiff Pwl Damp Wedge Angle Force LB  Mu
! 14  0   0  37.5  2.898E03 1.0E04 0.40
! modified for new type 6.7, MU1 for slope Mu2 for Face, T=Toe out, F=Toe in
! Ch # Pwl Stf Pwl Damp Wedge Ang Force LB  Mu1 Mu2 Toe
! 14  0 0 3.75E+01 2.90E+03 1.00E+04 4.00E-01 4.00E-01 .T.
! 0.50 inch wedge rise (1.8393 - 0.50 = 1.3393 * 1979 = 2650)
! Ch # Pwl Stiff Pwl Damp Wedge Angle Force LB  Mu
! 14  0   0  37.5  2.650E03 1.0E04 0.40
! 0.75 inch wedge rise (1.8393 - 0.75 = 1.0893 * 1979 = 2155)
! Ch # Pwl Stiff Pwl Damp Wedge Angle Force LB  Mu
! 14  0   0  37.5  2.155E03 1.0E04 0.40
!
! Option for a VARIABLE DAMPED TRUCK design
! Ch # Pwl Stf Pwl Damp Wedge Ang Force LB  Mu1 Mu2 Toe
! 14  17   0  32.0  0.0 1.0E04 0.40 0.40 .T.
! 6.8 Wedge
! Ch # Pwl Stiff PwlDamp Wedge Angle Force  C1  C2  Mu Face Mu Back Toe Long K
 14 17   0  35.0  0.0 1.0E6 1.0E3 0.32  0.32 .T. 1.0E5
!
!****************** Bearing Adapter Side Frame to Axle ********************
! Vertical side frame to axle connections with friction, type 6.5
 15 18 0        1.00E+06 1.00E+03 5.00E-01
! Vertical damping for bearing adapters with gap element
 16  0 19 1.00E+03 3.14E-02
! Longitudinal stiffness and stops
 17 20 0 1.00E+09 -1.00E+09
! Lateral stiffness and stops
 18 21 0 1.00E+09 -1.00E+09
```

```
! Yaw stiffness and stops
 19 22 0 1.00E+09 -1.00E+09
! Dummy Center Plate Roll/Pitch/Yaw Connection
 20  0 0 1.00E+09 -1.00E+09
```

For type 4 - axle to track characteristics, give a lateral stiffness and damping and identification numbers for the vertical PWL stiffness and damping, then for each, list an identification number, the nominal wheel radius, WRAD, a wheel rotation index, INDWH, .F. for solid, .T. for independent wheels, traction torque input nos., ITRQ, for left and right wheels, 0 for none, and, for independent wheels, KWHL, DWHL, the axle torsional stiffness and damping.

```
 Axle #  WRAD  INDWH  ITRQ-L ITRQ-R  KWHL  DWHL
---------------------------------------------------------------------------
$\WHEEL/RAIL ELEMENT TIE
$ 1.000E+05 1.000E+02 1.000E+05 1.000E+02 2.500E+05 2.500E+02
\WHEEL/RAIL ELEMENT
  1.E5 1.E2 2.5E5 2.5E2
 1  18.000  .F.   0   0
 2  18.000  .F.   0   0
 3  18.000  .F.   0   0
 4  18.000  .F.   0   0
```

For each piecewise linear function, list the identification number, the number of break points, and the ordinate, lb or in-lb, over abscissa, inches or rad, at each break point.

Note - extension is assumed to be positive for both ordinate and abscissa and 0.0 for the first break point indicates symmetry about the origin.

```
 PWL IBP Ordinates over Abscissae
---------------------------------------------------------------------------
\PWL DATA
```

```
! ************************ Couplers **********************************
! Coupler to Ground Lead and Trail Ends
 1 2 0.0000E+00 1.0000E+01
   0.000000 1.000000
! Tow Rope to Ground Through C.G.
! 1500 LB/IN
 2 2 0.0000E+00 1.5000E+03
   0.000000 1.000000
 3 2 0.0000E+00 1.5000E+02
   0.000000 1.000000
! ********************* Center plate Connections**************************
! Longitudinal and lateral rim normal stiffness
! Steel on steel, with 80 lb/in +/-0.125 inch gap
 4 4 -1.1010E+03 -1.0000E+01 0.0000E+00 0.0000E+00
   -0.126000 -0.125000 0.000000 1.000000
! Vertical lift off spring for center plate
! The center plate stiffness has been increased from 1xE6 to 1xE7 to
! improve the roll calculation.
! with initial offsets
!
!Empty
! 5 3 -4.4340E+03 0.0000E+00 0.0000E+00
!   0.000000 0.0004434 1.000000
! Loaded
 5 3 -2.5509E+04 0.0000E+00 0.0000E+00
   0.000000 0.002351 1.000000
! Damping of center plate
 6 2 0.0000E+00 1.0000E+03
   0.000000 1.000000
! ********************* Roller Side Bearings ******************************
! Lift off spring for side bearings
! 7 3 -1.0000E+06 0.0000E+00 0.0000E+00
!   -1.000000 0.000000 1.000000
```

```
! Damping of side bearings
! 8 2 0.0000E+00 0.0000E+00
!   0.000000 1.000000
! ********************* Constant Contact Side Bearings *********************
! TCC-III-45 Long Travels
 9 7 -8.8000E+03 -7.8000E+03 -5.8000E+03 -4.3000E+03 -1.8000E+03 0.0000E+00
0.0000E+00
   -0.626000 -0.625000 -0.312500 0.000000 0.500000 1.000000 2.000000
! CCSB Damping
 10 3 0.0000E+00 1.0000E+03 1.0000E+03
   0.000000 0.050000 1.000000
! ********************* Bolster to Side Frame Connections *******************
! Longitudinal
 11 2 0.0000E+00 1.0000E+06
   0.000000 1.000000
 12 2 0.0000E+00 1.0000E+03
   0.000000 1.000000
! Pitch Stiffness and Stops Mid Tolerance is Approx +/- 2.4 Degrees=0.042mRad
 13 3 0.0000E+00 0.0000E+00 6.4000E+07
   0.000000 0.042000 1.042000
! ****************** Warp resistance ************************************
! worn truck
! Warp resistance for bolster to side frame
! 14  3  0.0  5.25E04 6.924E05
!     0.0  0.030  0.040
! New truck
! Warp resistance for bolster to side frame
 14 3 0.0000E+00 2.5500E+05 8.9500E+05
   0.000000 0.030000 0.040000
! Stiff H-frame truck
! Warp resistance for bolster to side frame
! 14  3  0.0  1.275E06 1.915E06
!     0.0  0.030  0.040
```

! ****************************** Loaded********************************

! LATERAL STIFFNESS OF BOLSTER TO SIDE FRAME CONNECTION FOR ONE OF 4 EFFECTIVE SPRINGS in pounds and inches

! 7-D5 OUTER 6-D5 INNER SPRINGS I INNER CONTROL COILS, 2-B432 O OUTER CONTROL 2-B433 I INNER CONTROL COILS

15 3 0.000E+0 1.756E+3 1.018E+5

0.0000 0.5000 0.6000

! VERTICAL SUSPENSION WITH STATIC DEFLECTIONS FOR 4 EQUIVALENT SPRINGS

! 7-D5 OUTER 6-D5 INNER SPRINGS

! IN LBS AND INCHES

16 6 -4.577E+4 -2.077E+4 -1.102E+4 -1.050E+2 0.000E+0 0.000E+0

-1.8396 -1.7396 0.0000 1.9479 2.0104 3.7604

! FRICTION WEDGE CONTROL SPRING STIFFNESS FOR EQUIVALENT SPRINGS

! 2-B432 O OUTER CONTROL 2-B433 I INNER CONTROL COILS

17 7 -5.668E+4 -6.681E+3 -4.087E+3 -1.183E+3 -1.090E+3 -6.444E+1 0.000E+0

-1.8396 -1.7396 0.0000 1.9479 2.0104 2.6979 3.7604

! ******************************** Empty *******************************

! LATERAL STIFFNESS OF BOLSTER TO SIDE FRAME CONNECTION FOR ONE OF 4 EFFECTIVE SPRINGS in pounds and inches

! 7-D5 OUTER 6-D5 INNER SPRINGS I INNER CONTROL COILS, 2-B432 O OUTER CONTROL 2-B433 I INNER CONTROL COILS

! 15 3 0.000E+0 1.356E+3 1.014E+5

! 0.0000 0.5000 0.6000

! VERTICAL SUSPENSION WITH STATIC DEFLECTIONS FOR 4 EQUIVALENT SPRINGS

! 7-D5 OUTER 6-D5 INNER SPRINGS I INNER CONTROL COILS

! IN LBS AND INCHES

! 16 6 -4.577E+4 -2.077E+4 -2.601E+3 -1.050E+2 0.000E+0 0.000E+0

! -3.3419 -3.2419 0.0000 0.4456 0.5081 2.2581

! FRICTION WEDGE CONTROL SPRING STIFFNESS FOR EQUIVALENT SPRINGS

! 2-B432 O OUTER CONTROL 2-B433 I INNER CONTROL COILS

! 17 7 -5.668E+4 -6.681E+3 -1.847E+3 -1.183E+3 -1.090E+3 -6.444E+1 0.000E+0

! -3.3419 -3.2419 0.0000 0.4456 0.5081 1.1956 2.2581

```
!****************** Bearing Adapter Side Frame to Axle ********************
! Vertical Bearing adapter connection with offset for static load
!
!Empty
! 18 3 -3.8121E+03 0.0000E+00 0.0000E+00
!   0.000000 0.003812 1.000000
! Loaded
 18 3 -1.3350E+04 0.0000E+00 0.0000E+00
   0.000000 0.013350 1.000000
! Vertical Bearing adapter damping
 19 2 0.0000E+00 1.0000E+03
   0.000000 1.000000
! Bearing adapter stops
! Longitudinal Stiffness with Stops
 20 3 0.0000E+00 1.0000E+00 1.0000E+03
   0.000000 0.046800 0.047800
! Lateral Stiffness with Stops
 21 3 0.0000E+00 1.0000E+00 1.0000E+03
   0.000000 0.250000 0.251000
! Yaw Stiffness with Stops
 22 3 0.0000E+00 0.0000E+00 6.4000E+05
   0.000000 0.030000 0.040000
```

Empty Flat Car

System file (.SYS) for NUCARS Version 2014

```
==========================================
 \SYSTEM TITLE
```
Empty 70T BulkHead FlatCar w/CCSB LT w/optional Roller Side Bearings,

Give the number of bodies, then for each, list the number, name, up to 15 characters in single quotes, and c.g. position, relative to a chosen datum, followed by the number and list of degrees of freedom required (from 1=x, 2=y, 3=z, 4=phi, 5=theta, 6=psi, 7=epsx, 8=epsy, 9=epsz), and the mass and inertias in roll, pitch, and yaw. The degrees of freedom required for each axle are 2, 3, 4, and 6. A longitudinal degree of freedom, 1, is optional.

```
 Body # ' 15 Char Name '   C.G. Posn in X, Y, & Z
          No. & DoF List   Mass, Roll, Pitch, & Yaw Inertia
--------------------------------------------------------------------------
\BODY DATA
 11
! Data from FRA/ORD-81/75.2 DOT-TSC-FRA-81-16.II
! Empty weight 60290 pounds
! Loaded weight 192870 pounds
! Trucks weight 18630 pounds
! Empty
 1 'Empty Main Body'  -303.5000  0.0000  42.1
 6 1 2 3 4 5 6     107.90 177779 4013047  4054890
! Loaded
! 1 'LoadedMain Body'  -291.7500  0.0000  89.30
! 6 1 2 3 4 5 6     451.29 1412863 15254703 14786887
 2 'Leading Bolster'   -34.0000  0.0000  16.5000
 6 1 2 3 4 5 6      3.530           2569.816 186.28 2595.92
 3 'Trailng Bolster'  -573.0000  0.0000  16.5000
 6 1 2 3 4 5 6      3.530           2569.816 186.28 2595.92
 4 'Lead Lft Sframe'   -34.0000 39.0000  16.5000
 6 1 2 3 4 5 6      2.675  765.57 1327.83 1208.00
 5 'Lead Rgt Sframe'   -34.0000 -39.0000  16.5000
```

```
 6 1 2 3 4 5 6      2.675  765.57 1327.83 1208.00
 6 'Trail Lt Sframe'  -573.0000 39.0000  16.5000
 6 1 2 3 4 5 6      2.675  765.57 1327.83 1208.00
 7 'Trail Rt Sframe'  -573.0000 -39.0000  16.5000
 6 1 2 3 4 5 6      2.675  765.57 1327.83 1208.00
 8 ' Axle number 1 '   0.0000  0.0000  16.5000
 5 1 2 3 4 6      7.624 7156.50 1232.92 7156.50
 9 ' Axle number 2 '   -68.0000  0.0000  16.5000
 5 1 2 3 4 6      7.624 7156.50 1232.92 7156.50
 10 ' Axle number 3 '  -539.0000  0.0000  16.5000
 5 1 2 3 4 6      7.624 7156.50 1232.92 7156.50
 11 ' Axle number 4 '  -607.0000  0.0000  16.5000
 5 1 2 3 4 6      7.624 7156.50 1232.92 7156.50

\CONNECTION DATA
 109
! Location of Couplers to Ground, Set to 1E1 lb/in
 1 'Coupler to Grnd' 1 1 0  36.0000 0.0000 33.0000 1 1
 2 'Coupler to Grnd' 1 1 0 -643.0000 0.0000 33.0000 1 1
! Tow Rope to Ground through C.G. location on the Car Body
 3 'Tow Rope - Grnd' 1 1 0 -303.5000 0.0000 41.1000 1 2
! ********************** LEADING TRUCK *********************************
! Lead Truck Lateral and longitudinal connections for 16" center plate using
! 6.2 line friction element for rim friction at four corners
 101 'Ld CB-Bl LgY LL' 6.2 2 1 -34.0000 7.0000 25.0625 2 1 3
 102 'Ld CB-Bl LgY LR' 6.2 1 2 -34.0000 -7.0000 25.0625 2 1 3
 103 'Ld CB-Bl LtX Fr' 6.2 2 1 -27.0000 0.0000 25.0625 1 2 3
 104 'Ld CB-Bl LtX Tr' 6.2 1 2 -41.0000 0.0000 25.0625 1 2 3
! Lead Truck Vertical and rotational connections for center plates using a
! surface friction element
 105 'Ld CB-Bl Vt/Y F' 6.5 1 2 -27.0000 0.0000 25.0625 3 1 2 4
 106 'Ld CB-Bl Vt/Y B' 6.5 1 2 -41.0000 0.0000 25.0625 3 1 2 4
 107 'Ld CB-Bl Vt/X L' 6.5 1 2 -34.0000 7.0000 25.0625 3 1 2 4
```

```
 108 'Ld CB-Bl Vt/X R' 6.5 1 2 -34.0000 -7.0000 25.0625 3 1 2 4
! Lead truck vertical centerplate dampers, gap connection
 109 'Ld CB-Bl Vt/Y F' 1.2 1 2 -27.0000 0.0000 25.0625 3 5
 110 'Ld CB-Bl Vt/Y B' 1.2 1 2 -41.0000 0.0000 25.0625 3 5
 111 'Ld CB-Bl Vt/X L' 1.2 1 2 -34.0000 7.0000 25.0625 3 5
 112 'Ld CB-Bl Vt/X R' 1.2 1 2 -34.0000 -7.0000 25.0625 3 5
! Lead Truck Vertical roller side bearing connections using a gap element
!113 'Ld Bol SB Lt Vt' 1.2 1 2 -34.0000 25.0000 29.3000 3 6
!114 'Ld Bol SB Rt Vt' 1.2 1 2 -34.0000 -25.0000 29.3000 3 6
! Lead Truck Constant Contact Side Bearings
 115 'Ld Bol SB Lt Vt' 6.2 1 2 -34.0000 -25.0000 29.3000 3 1 7
 116 'Ld Bol SB Rt Vt' 6.2 1 2 -34.0000 -25.0000 29.3000 3 1 7
! Lead truck Long.,Pitch, and Yaw bolster to side frame connections
 117 'Ld L Bol-SF LPY' 1.1 2 4 -34.0000 39.0000 16.5000 3 1 5 6 8 9 10
 118 'Ld R Bol-SF LPY' 1.1 2 5 -34.0000 -39.0000 16.5000 3 1 5 6 8 9 10
! Lead Truck Vertical bolster to side frame connections
! split into 4 seperate springs at each nest, dropped down 5"
 119 'Ld L Bol-SF V 1' 1.3 2 4 -30.2500 35.2500 14.5000 3 2 3 4 11 12 13
 120 'Ld R Bol-SF V 1' 1.3 2 5 -30.2500 -35.2500 14.5000 3 2 3 4 11 12 13
 121 'Ld L Bol-SF V 2' 1.3 2 4 -30.2500 42.7500 14.5000 3 2 3 4 11 12 13
 122 'Ld R Bol-SF V 2' 1.3 2 5 -30.2500 -42.7500 14.5000 3 2 3 4 11 12 13
 123 'Ld L Bol-SF V 3' 1.3 2 4 -37.7500 35.2500 14.5000 3 2 3 4 11 12 13
 124 'Ld R Bol-SF V 3' 1.3 2 5 -37.7500 -35.2500 14.5000 3 2 3 4 11 12 13
 125 'Ld L Bol-SF V 4' 1.3 2 4 -37.7500 42.7500 14.5000 3 2 3 4 11 12 13
 126 'Ld R Bol-SF V 4' 1.3 2 5 -37.7500 -42.7500 14.5000 3 2 3 4 11 12 13
! Lead Truck 2D Friction wedge connection between bolster and side frame
 127 'Ld Bol-SF LL Wg' 6.8 2 4 -25.5000 39.0000 16.5000 3 2 14
 128 'Ld Bol-SF LR Wg' 6.8 2 5 -25.5000 -39.0000 16.5000 3 2 14
 129 'Ld Bol-SF TL Wg' 6.8 2 4 -42.5000 39.0000 16.5000 3 2 14
 130 'Ld Bol-SF TR Wg' 6.8 2 5 -42.5000 -39.0000 16.5000 3 2 14
! Lead Truck Vertical surface friction element for side frame to axle
! connections elements are placed +/- 3.0 inches apart to react roll, and
! pitch of the side frame
```

131 'SdFm-Ax 1 L V L' 6.5 4 8 0.0000 42.0000 22.5000 3 1 2 15
132 'SdFm-Ax 1 L V R' 6.5 4 8 0.0000 36.0000 21.0000 3 1 2 15
133 'SdFm-Ax 1 R V R' 6.5 5 8 0.0000 -42.0000 21.0000 3 1 2 15
134 'SdFm-Ax 1 R V L' 6.5 5 8 0.0000 -36.0000 21.0000 3 1 2 15
135 'SdFm-Ax 2 L V L' 6.5 4 9 -68.0000 42.0000 21.0000 3 1 2 15
136 'SdFm-Ax 2 L V R' 6.5 4 9 -68.0000 36.0000 21.0000 3 1 2 15
137 'SdFm-Ax 2 R V R' 6.5 5 9 -68.0000 -42.0000 21.0000 3 1 2 15
138 'SdFm-Ax 2 R V L' 6.5 5 9 -68.0000 -36.0000 21.0000 3 1 2 15
! Lead Truck Vertical dampers for surface friction elements
139 'SdFm-Ax 1 L V L' 1.2 4 8 0.0000 42.0000 21.0000 3 16
140 'SdFm-Ax 1 L V R' 1.2 4 8 0.0000 36.0000 21.0000 3 16
141 'SdFm-Ax 1 R V R' 1.2 5 8 0.0000 -42.0000 21.0000 3 16
142 'SdFm-Ax 1 R V L' 1.2 5 8 0.0000 -36.0000 21.0000 3 16
143 'SdFm-Ax 2 L V L' 1.2 4 9 -68.0000 42.0000 21.0000 3 16
144 'SdFm-Ax 2 L V R' 1.2 4 9 -68.0000 36.0000 21.0000 3 16
145 'SdFm-Ax 2 R V R' 1.2 5 9 -68.0000 -42.0000 21.0000 3 16
146 'SdFm-Ax 2 R V L' 1.2 5 9 -68.0000 -36.0000 21.0000 3 16
! Lead truck side frame to axle longitudinal, lateral and yaw Stops
147 'SdFm-Ax 1 L V L' 1.1 4 8 0.0000 39.0000 21.0000 3 1 2 6 17 18 19
148 'SdFm-Ax 1 R V R' 1.1 5 8 0.0000 -39.0000 21.0000 3 1 2 6 17 18 19
149 'SdFm-Ax 2 L V L' 1.1 4 9 -68.0000 39.0000 21.0000 3 1 2 6 17 18 19
150 'SdFm-Ax 2 R V R' 1.1 5 9 -68.0000 -39.0000 21.0000 3 1 2 6 17 18 19
! Lead Truck Wheel/rail connections
151 'Ax 1 Lt Wh/Rail' 4 8   0.0000 29.7500 0.0000 1
152 'Ax 1 Rt Wh/Rail' 4 8   0.0000 -29.7500 0.0000 1
153 'Ax 2 Lt Wh/Rail' 4 9 -68.0000 29.7500 0.0000 2
154 'Ax 2 Rt Wh/Rail' 4 9 -68.0000 -29.7500 0.0000 2
155 'Dummy Ctr Plt 1' 1.1 1 2 -34.0000 0.0000 22.7000 3 4 5 6 20 20 20
! ********************** TRAILING TRUCK ********************************
! Trail Truck Lateral and longitudinal connections for 16" center plate using
! 6.2 line friction element for rim friction at four corners
201 'Tr CB-Bl LgY LL' 6.2 3 1 -573.0000 7.0000 25.0625 2 1 3
202 'Tr CB-Bl LgY LR' 6.2 1 3 -573.0000 -7.0000 25.0625 2 1 3

```
 203 'Tr CB-Bl LtX Fr' 6.2 3 1 -566.0000 0.0000 25.0625 1 2 3
 204 'Tr CB-Bl LtX Tr' 6.2 1 3 -580.0000 0.0000 25.0625 1 2 3
! Trail Truck Vertical and rotational connections for center plates using a
! surface friction element
 205 'Tr CB-Bl Vt/Y F' 6.5 1 3 -566.0000 0.0000 25.0625 3 1 2 4
 206 'Tr CB-Bl Vt/Y B' 6.5 1 3 -580.0000 0.0000 25.0625 3 1 2 4
 207 'Tr CB-Bl Vt/X L' 6.5 1 3 -573.0000 7.0000 25.0625 3 1 2 4
 208 'Tr CB-Bl Vt/X R' 6.5 1 3 -573.0000 -7.0000 25.0625 3 1 2 4
! Trail truck vertical centerplate dampers, gap connection
 209 'Tr CB-Bl Vt/Y F' 1.2 1 3 -566.0000 0.0000 25.0625 3 5
 210 'Tr CB-Bl Vt/Y B' 1.2 1 3 -580.0000 0.0000 25.0625 3 5
 211 'Tr CB-Bl Vt/X L' 1.2 1 3 -573.0000 7.0000 25.0625 3 5
 212 'Tr CB-Bl Vt/X R' 1.2 1 3 -573.0000 -7.0000 25.0625 3 5
! Trail Truck Vertical roller side bearing connections using a gap element
!213 'Tr Bol SB Lt Vt' 1.2 1 3 -573.5000 25.0000 29.3000 3 6
!214 'Tr Bol SB Rt Vt' 1.2 1 3 -573.5000 -25.0000 29.3000 3 6
! Trail Lead Truck Constant Contact Side Bearings
 215 'Tr Bol SB Lt Vt' 6.2 1 3 -573.0000 25.0000 29.3000 3 1 7
 216 'Tr Bol SB Rt Vt' 6.2 1 3 -573.0000 25.0000 29.3000 3 1 7
! Trail truck Long.,Pitch, and Yaw bolster to side frame connections
 217 'Tr L Bol-SF LPY' 1.1 3 6 -573.0000 39.0000 16.5000 3 1 5 6 8 9 10
 218 'Tr R Bol-SF LPY' 1.1 3 7 -573.0000 -39.0000 16.5000 3 1 5 6 8 9 10
! Trail Truck Vertical bolster to side frame connections
! split into 4 seperate springs at each nest, dropped down 5"
 219 'Tr L Bol-SF V 1' 1.3 3 6 -569.2500 35.2500 14.5000 3 2 3 4 11 12 13
 220 'Tr R Bol-SF V 1' 1.3 3 7 -569.2500 -35.2500 14.5000 3 2 3 4 11 12 13
 221 'Tr L Bol-SF V 2' 1.3 3 6 -569.2500 42.7500 14.5000 3 2 3 4 11 12 13
 222 'Tr R Bol-SF V 2' 1.3 3 7 -569.2500 -42.7500 14.5000 3 2 3 4 11 12 13
 223 'Tr L Bol-SF V 3' 1.3 3 6 -576.7500 35.2500 14.5000 3 2 3 4 11 12 13
 224 'Tr R Bol-SF V 3' 1.3 3 7 -576.7500 -35.2500 14.5000 3 2 3 4 11 12 13
 225 'Tr L Bol-SF V 4' 1.3 3 6 -576.7500 42.7500 14.5000 3 2 3 4 11 12 13
 226 'Tr R Bol-SF V 4' 1.3 3 7 -576.7500 -42.7500 14.5000 3 2 3 4 11 12 13
! Trail Truck 2D Friction wedge connection between bolster and side frame
```

227 'Tr Bol-SF LL Wg' 6.8 3 6 -564.5000 39.0000 16.5000 3 2 14
228 'Tr Bol-SF LR Wg' 6.8 3 7 -564.5000 -39.0000 16.5000 3 2 14
229 'Tr Bol-SF TL Wg' 6.8 3 6 -581.5000 39.0000 16.5000 3 2 14
230 'Tr Bol-SF TR Wg' 6.8 3 7 -581.5000 -39.0000 16.5000 3 2 14
! Trail Truck Vertical surface friction element for side frame to axle
! connections elements are placed +/- 3.0 inches apart to react roll, and
! pitch of the side frame
231 'SdFm-Ax 3 L V L' 6.5 6 10 -539.0000 42.0000 21.0000 3 1 2 15
232 'SdFm-Ax 3 L V R' 6.5 6 10 -539.0000 36.0000 21.0000 3 1 2 15
233 'SdFm-Ax 3 R V R' 6.5 7 10 -539.0000 -42.0000 21.0000 3 1 2 15
234 'SdFm-Ax 3 R V L' 6.5 7 10 -539.0000 -36.0000 21.0000 3 1 2 15
235 'SdFm-Ax 4 L V L' 6.5 6 11 -607.0000 42.0000 21.0000 3 1 2 15
236 'SdFm-Ax 4 L V R' 6.5 6 11 -607.0000 36.0000 21.0000 3 1 2 15
237 'SdFm-Ax 4 R V R' 6.5 7 11 -607.0000 -42.0000 21.0000 3 1 2 15
238 'SdFm-Ax 4 R V L' 6.5 7 11 -607.0000 -36.0000 21.0000 3 1 2 15
! Trail Truck Vertical dampers for surface friction elements
239 'SdFm-Ax 3 L V L' 1.2 6 10 -539.0000 42.0000 21.0000 3 16
240 'SdFm-Ax 3 L V R' 1.2 6 10 -539.0000 36.0000 21.0000 3 16
241 'SdFm-Ax 3 R V R' 1.2 7 10 -539.0000 -42.0000 21.0000 3 16
242 'SdFm-Ax 3 R V L' 1.2 7 10 -539.0000 -36.0000 21.0000 3 16
243 'SdFm-Ax 4 L V L' 1.2 6 11 -607.0000 42.0000 21.0000 3 16
244 'SdFm-Ax 4 L V R' 1.2 6 11 -607.0000 36.0000 21.0000 3 16
245 'SdFm-Ax 4 R V R' 1.2 7 11 -607.0000 -42.0000 21.0000 3 16
246 'SdFm-Ax 4 R V L' 1.2 7 11 -607.0000 -36.0000 21.0000 3 16
! Trail truck side frame to axle longitudinal, lateral and yaw Stops
247 'SdFm-Ax 3 L V L' 1.1 6 10 -539.0000 39.0000 21.0000 3 1 2 6 17 18 19
248 'SdFm-Ax 3 R V R' 1.1 7 10 -539.0000 -39.0000 21.0000 3 1 2 6 17 18 19
249 'SdFm-Ax 4 L V L' 1.1 6 11 -607.0000 39.0000 21.0000 3 1 2 6 17 18 19
250 'SdFm-Ax 4 R V R' 1.1 7 11 -607.0000 -39.0000 21.0000 3 1 2 6 17 18 19
! Trail Truck Wheel/rail connections
251 'Ax 3 Lt Wh/Rail' 4 10 -539.0000 29.7500 0.0000 3
252 'Ax 3 Rt Wh/Rail' 4 10 -539.0000 -29.7500 0.0000 3
253 'Ax 4 Lt Wh/Rail' 4 11 -607.0000 29.7500 0.0000 4

```
 254 'Ax 4 Rt Wh/Rail' 4 11  -607.0000 -29.7500 0.0000 4
 255 'Dummy Ctr Plt 2' 1.1 1 3 -573.0000 0.0000 22.7000 3 4 5 6 20 20 20
```

For each connection characteristic, list its number, identification numbers for the piecewise linear stiffness and damping characteristics, respectively, zero if absent, and the force, moment, or stroke limits in extn and compn, (if no limit exists, set the values outside the expected range).

```
 Pair # Stiffness & Damping F/S-extn. F/S-comp. K/D-parameters
--------------------------------------------------------------------------
\CHARACTERISTIC DATA
! ************************* Couplers ***********************************
 1  1 0 1.00E+09 -1.00E+09
! Tow Rope
 2  2 3 1.00E+09 -1.00E+09
! ********************** Center Plate **********************************
! Center plate longitudinal and lateral rim friction
 3  4 0 1.00E+00 -1.00E+00 0.00E+00 1.00E+06 1.00E+03 5.00E-01
! Centerplate vertical with longitudinal and lateral surface friction
!
! Cw = Car weight
! Mu1 friction value for the center plate
! Mu2 effective friction value for this simulation
! R= radius of center plate
!
! Charct. #5 The normal formula for calculating the center plate breakout
! torque for one bowl is (Cw*Mu1*R)/3. This model assumes all loads are
! carried at the lateral edges of the center plate. This produces a breakout
! torque equal to (Mu2*Cw*R)/4 for each edge. Setting the two equations
! equal to each other produces the effective Mu, R relationship. Therefore,
! Mu1*2/3 = Mu2.
! Center Plate Lube 0.1 2/3*.1 = 0.0666
! Center Plate Lube 0.2 2/3*.2 = 0.1333
```

```
! Center Plate Lube 0.3 2/3*.3 = 0.2000
! Center Plate Lube 0.4 2/3*.4 = 0.2666
! Center Plate Lube 0.5 2/3*.5 = 0.3333
! 4 5   0  1.0E06 1.0E03 0.0666
! 4 5   0  1.0E06 1.0E03 0.3333
 4  5 0       1.00E+06 1.00E+03 2.67E-01
! Centerplate damping, type 1.2 connection
 5  0 6 1.00E+03 2.96E-04
!
! ********************* Roller Side Bearings ******************************
! Gap element at for roller side bearings, -0.250 accounts for deflection of
! center plate springs.
! 6  7 8 1.00E+03 -2.50E-01
! ********************* Constant Contact Side Bearings *********************
 7  9 10 3.00E+00 -3.00E+00 0.00E+00 1.00E+06 1.00E+03 3.00E-01
! ********************* Bolster to Side Frame Connections ******************
! Longitudinal
 8 11 12 1.00E+09 -1.00E+09
! Pitch stiffness and stops
 9 13 0 1.00E+09 -1.00E+09
! Warp/torsion
 10 14 0 1.00E+09 -1.00E+09
! Lateral stiffness and stops
 11 15 0 1.00E+09 -1.00E+09
! Vertical Springs
 12 16 0 0.00E+00 -1.00E+09
! Dummy roll characteristic for type 1.3 connection
 13  0 0 1.00E+09 -1.00E+09
! # 4 is a 6.3 wedge element with pwl numbers, wedge angle, force, LVB,
! and friction, Constant damped truck is 1979 lb/in in the control coils
! at zero wedge rise the control coils are compressed 1.8393 inches
! 0.0 inch wedge rise
! Ch # Pwl Stiff Pwl Damp Wedge Angle Force LB  Mu
```

```
! 14  0   0  37.5  3.640E03 1.0E04 0.40
! 0.25 inch wedge rise (1.8393 - 0.25 = 1.5893 * 1979 = 3145)
! Ch # Pwl Stiff Pwl Damp Wedge Angle Force LB  Mu
! 14  0   0  37.5  3.1450E03 1.0E04 0.40
! 0.375 inch wedge rise (1.8393 -.375=1.4643*1979=2898)
! Ch # Pwl Stiff Pwl Damp Wedge Angle Force LB  Mu
! 14  0   0  37.5  2.898E03 1.0E04 0.40
! modified for new type 6.7, MU1 for slope Mu2 for Face, T=Toe out, F=Toe in
! Ch # Pwl Stf Pwl Damp Wedge Ang Force LB  Mu1 Mu2 Toe
! 14  0 0 3.75E+01 2.90E+03 1.00E+04 4.00E-01 4.00E-01 .T.
! 0.50 inch wedge rise (1.8393 - 0.50 = 1.3393 * 1979 = 2650)
! Ch # Pwl Stiff Pwl Damp Wedge Angle Force LB  Mu
! 14  0   0  37.5  2.650E03 1.0E04 0.40
! 0.75 inch wedge rise (1.8393 - 0.75 = 1.0893 * 1979 = 2155)
! Ch # Pwl Stiff Pwl Damp Wedge Angle Force LB  Mu
! 14  0 0 3.75E+01 2.16E+03 1.00E+04 4.00E-01 0.00E+00
!
! Option for a VARIABLE DAMPED TRUCK design
! Ch # Pwl Stf Pwl Damp Wedge Ang Force LB  Mu1 Mu2 Toe
! 14  17   0  32.0  0.0 1.0E04 0.40 0.40 .T.
! 6.8 Wedge
! Ch # Pwl Stiff PwlDamp Wedge Angle Force  C1  C2  Mu Face Mu Back Toe Long K
 14  0   0  37.5  3.640E03 1.0E6 1.0E3 0.40  0.40 .T. 1.0E5
! 14 17   0  37.5  0.0  1.0E6 1.0E3 0.32  0.32 .T. 1.0E5
!
!****************** Bearing Adapter Side Frame to Axle ********************
! Vertical side frame to axle connections with friction, type 6.5
 15 18 0        1.00E+06 1.00E+03 0.50
! Vertical damping for bearing adapters with gap element
 16  0 19 1.00E+03 3.03E-03
! Longitudinal stiffness and stops
 17 20 0 1.00E+09 -1.00E+09
! Lateral stiffness and stops
```

```
 18 21 0 1.00E+09 -1.00E+09
! Yaw stiffness and stops
 19 22 0 1.00E+09 -1.00E+09
! Dummy Center Plate Roll/Pitch/Yaw Connection
 20  0 0 1.00E+09 -1.00E+09
```

For type 4 - axle to track characteristics, give a lateral stiffness and
damping and identification numbers for the vertical PWL stiffness and damping,
then for each, list an identification number, the nominal wheel radius, WRAD,
a wheel rotation index, INDWH, .F. for solid, .T. for independent wheels,
traction torque input nos., ITRQ, for left and right wheels, 0 for none, and,
for independent wheels, KWHL, DWHL, the axle torsional stiffness and damping.

```
 Axle #  WRAD  INDWH  ITRQ-L ITRQ-R  KWHL  DWHL
--------------------------------------------------------------------------
$\WHEEL/RAIL ELEMENT TIE
$ 1.000E+05 1.000E+02 1.000E+05 1.000E+02 2.500E+05 2.500E+02
\WHEEL/RAIL ELEMENT
 1.000E+05 1.000E+02 2.500E+05 2.500E+02
 1  16.500  .F.   0   0
 2  16.500  .F.   0   0
 3  16.500  .F.   0   0
 4  16.500  .F.   0   0
```

For each piecewise linear function, list the identification number, the number
of break points, and the ordinate, lb or in-lb, over abscissa, inches or rad,
at each break point.

Note - extension is assumed to be positive for both ordinate and abscissa and
  0.0 for the first break point indicates symmetry about the origin.

```
 PWL IBP Ordinates over Abscissae
--------------------------------------------------------------------------
```

```
\PWL DATA
! ************************ Couplers ***********************************
! Coupler to Ground Lead and Trail Ends
 1 2 0.0000E+00 1.0000E+01
   0.000000 1.000000
! Tow Rope to Ground Through C.G.
! 1500 LB/IN
 2 2 0.0000E+00 1.5000E+03
   0.000000 1.000000
 3 2 0.0000E+00 1.5000E+02
   0.000000 1.000000
! ********************* Center plate Connections *************************
! Longitudinal and lateral rim normal stiffness
! Steel on steel, with 80 lb/in +/-0.125 inch gap
 4 4 -1.1010E+03 -1.0000E+01 0.0000E+00 0.0000E+00
   -0.126000 -0.125000 0.000000 1.000000
! Vertical lift off spring for center plate
! The center plate stiffness has been increased from 1xE6 to 1xE7 to
! improve the roll calculation.
! with initial offsets
!Empty
 5 3 -2.9570E+03 0.0000E+00 0.0000E+00
   0.000000 0.0002957 1.000000
! Loaded
! 5 3 -1.9530E+04 0.0000E+00 0.0000E+00
!   0.000000 0.001953 1.000000
! Damping of center plate
 6 2 0.0000E+00 1.0000E+03
   0.000000 1.000000
! ********************* Roller Side Bearings ******************************
! Lift off spring for side bearings
! 7 3 -1.0000E+06 0.0000E+00 0.0000E+00
!   -1.000000 0.000000 1.000000
```

! Damping of side bearings

! 8 2 0.0000E+00 0.0000E+00

!   0.000000 1.000000

! ******************** Constant Contact Side Bearings ********************

! TCC-III-45 Long Travels

9 7 -8.8000E+03 -7.8000E+03 -5.8000E+03 -4.3000E+03 -1.8000E+03 0.0000E+00 0.0000E+00

-0.626000 -0.625000 -0.312500 0.000000 0.500000 1.000000 2.000000

! CCSB Damping

10 3 0.0000E+00 1.0000E+03 1.0000E+03

0.000000 0.050000 1.000000

! ******************** Bolster to Side Frame Connections ******************

! Longitudinal

11 2 0.0000E+00 1.0000E+06

0.000000 1.000000

12 2 0.0000E+00 1.0000E+03

0.000000 1.000000

! Pitch Stiffness and Stops Mid Tolerance is Approx +/- 2.4 Degrees=0.042mRad

13 3 0.0000E+00 0.0000E+00 6.4000E+07

0.000000 0.042000 1.042000

! ***************** Warp resistance ***********************************

! worn truck

! Warp resistance for bolster to side frame

! 14 3 0.0 5.25E04 6.924E05

!   0.0 0.030 0.040

! New truck

! Warp resistance for bolster to side frame

14 3 0.0000E+00 2.5500E+05 8.9500E+05

0.000000 0.030000 0.040000

! Stiff H-frame truck

! Warp resistance for bolster to side frame

! 14 3 0.0 1.275E06 1.915E06

!   0.0 0.030 0.040

```
! ********************************* Empty ******************************
! LATERAL STIFFNESS OF BOLSTER TO SIDE FRAME CONNECTION FOR ONE OF 4
EFFECTIVE SPRINGS in pounds and inches
 15 3 0.000E+0 1.281E+3 1.013E+5
   0.0000 0.5000 0.6000
! VERTICAL SUSPENSION WITH STATIC DEFLECTIONS FOR 4 EQUIVALENT
SPRINGS
! 7-D5 OUTER 6-D5 INNER SPRINGS
! IN LBS AND INCHES
 16 6 -4.577E+4 -2.077E+4 -2.775E+3 -1.050E+2 0.000E+0 0.000E+0
   -3.3110 -3.2110 0.0000 0.4765 0.5390 1.5390
! ********************************* Loaded **********************************
! LATERAL STIFFNESS OF BOLSTER TO SIDE FRAME CONNECTION FOR ONE OF 4
EFFECTIVE SPRINGS in pounds and inches
! 7-D5 OUTER 6-D5 INNER SPRINGS
! 15 3 0.000E+0 1.650E+3 1.017E+5
!   0.0000 0.5000 0.6000
! VERTICAL SUSPENSION WITH STATIC DEFLECTIONS FOR 4 EQUIVALENT
SPRINGS
! 7-D5 OUTER 6-D5 INNER SPRINGS
! IN LBS AND INCHES
! 16 6 -4.577E+4 -2.077E+4 -1.106E+4 -1.050E+2 0.000E+0 0.000E+0
!   -1.8323 -1.7323 0.0000 1.9552 2.0177 3.0177
!******************* Bearing Adapter Side Frame to Axle *********************
! Vertical Bearing adapter connection with offset for static load
!
!Empty
 18 3 -3.3225E+03 0.0000E+00 0.0000E+00
   0.000000 0.003032 1.000000
! Loaded
! 18 3 -1.1318E+04 0.0000E+00 0.0000E+00
!   0.000000 0.011318 1.000000
! Vertical Bearing adapter damping
 19 2 0.0000E+00 1.0000E+03
```

0.000000 1.000000

! Bearing adapter stops

! Longitudinal Stiffness with Stops

20 3 0.0000E+00 1.0000E+00 1.0000E+03

0.000000 0.046800 0.047800

! Lateral Stiffness with Stops

21 3 0.0000E+00 1.0000E+00 1.0000E+03

0.000000 0.250000 0.251000

! Yaw Stiffness with Stops

22 3 0.0000E+00 0.0000E+00 6.4000E+05

0.000000 0.030000 0.040000

Loaded Flat Car

System file (.SYS) for NUCARS Version 2014

==

\SYSTEM TITLE

Loaded 70T BulkHead FlatCar w/CCSB LT w/optional Roller Side Bearings,

Give the number of bodies, then for each, list the number, name, up to 15 characters in single quotes, and c.g. position, relative to a chosen datum, followed by the number and list of degrees of freedom required (from 1=x, 2=y, 3=z, 4=phi, 5=theta, 6=psi, 7=epsx, 8=epsy, 9=epsz), and the mass and inertias in roll, pitch, and yaw. The degrees of freedom required for each axle are 2, 3, 4, and 6. A longitudinal degree of freedom, 1, is optional.

```
 Body # ' 15 Char Name '   C.G. Posn in X, Y, & Z
           No. & DoF List   Mass, Roll, Pitch, & Yaw Inertia
------------------------------------------------------------------------
\BODY DATA
 11
! Data from FRA/ORD-81/75.2 DOT-TSC-FRA-81-16.II
! Empty weight 60290 pounds
! Loaded weight 192870 pounds
! Trucks weight 18630 pounds
! Empty
! 1 'Empty Main Body'  -303.5000  0.0000  42.1
! 6 1 2 3 4 5 6     107.90 177779 4013047  4054890
! Loaded
 1 'LoadedMain Body'  -303.5000  0.0000  89.30
 6 1 2 3 4 5 6     451.29 1412863 15254703 14786887
 2 'Leading Bolster'   -34.0000  0.0000  15.2500
 6 1 2 3 4 5 6      3.530           2569.816 186.28 2595.92
 3 'Trailng Bolster'  -573.0000  0.0000  15.2500
 6 1 2 3 4 5 6      3.530           2569.816 186.28 2595.92
 4 'Lead Lft Sframe'   -34.0000 39.0000  18.0000
 6 1 2 3 4 5 6      2.675  765.57 1327.83 1208.00
 5 'Lead Rgt Sframe'   -34.0000 -39.0000  18.0000
 6 1 2 3 4 5 6      2.675  765.57 1327.83 1208.00
```

```
 6 'Trail Lt Sframe'  -573.0000 39.0000  18.0000
 6 1 2 3 4 5 6      2.675  765.57 1327.83 1208.00
 7 'Trail Rt Sframe'  -573.0000 -39.0000  18.0000
 6 1 2 3 4 5 6      2.675  765.57 1327.83 1208.00
 8 ' Axle number 1 '   0.0000  0.0000  18.0000
 5 1 2 3 4 6      7.624 7156.50 1232.92 7156.50
 9 ' Axle number 2 '   -68.0000  0.0000  18.0000
 5 1 2 3 4 6      7.624 7156.50 1232.92 7156.50
 10 ' Axle number 3 '  -539.0000  0.0000  18.0000
 5 1 2 3 4 6      7.624 7156.50 1232.92 7156.50
 11 ' Axle number 4 '  -607.0000  0.0000  18.0000
 5 1 2 3 4 6      7.624 7156.50 1232.92 7156.50

\CONNECTION DATA
 109
! Location of Couplers to Ground, Set to 1E1 lb/in
 1 'Coupler to Grnd' 1 1 0  36.0000 0.0000 31.5000 1 1
 2 'Coupler to Grnd' 1 1 0 -643.0000 0.0000 31.5000 1 1
! Tow Rope to Ground through C.G. location on the Car Body
 3 'Tow Rope - Grnd' 1 1 0 -303.5000 0.0000 89.3000 1 2
! ********************** LEADING TRUCK ********************************
! Lead Truck Lateral and longitudinal connections for 16" center plate using
! 6.2 line friction element for rim friction at four corners
 101 'Ld CB-Bl LgY LL' 6.2 2 1 -34.0000 8.0000 23.7500 2 1 3
 102 'Ld CB-Bl LgY LR' 6.2 1 2 -34.0000 -8.0000 23.7500 2 1 3
 103 'Ld CB-Bl LtX Fr' 6.2 2 1 -26.0000 0.0000 23.7500 1 2 3
 104 'Ld CB-Bl LtX Tr' 6.2 1 2 -42.0000 0.0000 23.7500 1 2 3
! Lead Truck Vertical and rotational connections for center plates using a
! surface friction element
 105 'Ld CB-Bl Vt/Y F' 6.5 1 2 -26.0000 0.0000 23.7500 3 1 2 4
 106 'Ld CB-Bl Vt/Y B' 6.5 1 2 -42.0000 0.0000 23.7500 3 1 2 4
 107 'Ld CB-Bl Vt/X L' 6.5 1 2 -34.0000 8.0000 23.7500 3 1 2 4
 108 'Ld CB-Bl Vt/X R' 6.5 1 2 -34.0000 -8.0000 23.7500 3 1 2 4
```

```
! Lead truck vertical centerplate dampers, gap connection
 109 'Ld CB-Bl Vt/Y F' 1.2 1 2 -26.0000 0.0000 23.7500 3 5
 110 'Ld CB-Bl Vt/Y B' 1.2 1 2 -42.0000 0.0000 23.7500 3 5
 111 'Ld CB-Bl Vt/X L' 1.2 1 2 -34.0000 8.0000 23.7500 3 5
 112 'Ld CB-Bl Vt/X R' 1.2 1 2 -34.0000 -8.0000 23.7500 3 5
! Lead Truck Vertical roller side bearing connections using a gap element
!113 'Ld Bol SB Lt Vt' 1.2 1 2 -35.0000 25.0000 26.5500 3 6
!114 'Ld Bol SB Rt Vt' 1.2 1 2 -35.0000 -25.0000 26.5500 3 6
! Lead Truck Constant Contact Side Bearings
 115 'Ld Bol SB Lt Vt' 6.2 1 2 -34.0000 -25.0000 26.5500 3 1 7
 116 'Ld Bol SB Rt Vt' 6.2 1 2 -34.0000 -25.0000 26.5500 3 1 7
! Lead truck Long.,Pitch, and Yaw bolster to side frame connections
 117 'Ld L Bol-SF LPY' 1.1 2 4 -34.0000 39.0000 15.2500 3 1 5 6 8 9 10
 118 'Ld R Bol-SF LPY' 1.1 2 5 -34.0000 -39.0000 15.2500 3 1 5 6 8 9 10
! Lead Truck Vertical bolster to side frame connections
! split into 4 seperate springs at each nest, dropped down 5"
 119 'Ld L Bol-SF V 1' 1.3 2 4 -30.2500 35.2500 13.0000 3 2 3 4 11 12 13
 120 'Ld R Bol-SF V 1' 1.3 2 5 -30.2500 -35.2500 13.0000 3 2 3 4 11 12 13
 121 'Ld L Bol-SF V 2' 1.3 2 4 -30.2500 42.7500 13.0000 3 2 3 4 11 12 13
 122 'Ld R Bol-SF V 2' 1.3 2 5 -30.2500 -42.7500 13.0000 3 2 3 4 11 12 13
 123 'Ld L Bol-SF V 3' 1.3 2 4 -37.7500 35.2500 13.0000 3 2 3 4 11 12 13
 124 'Ld R Bol-SF V 3' 1.3 2 5 -37.7500 -35.2500 13.0000 3 2 3 4 11 12 13
 125 'Ld L Bol-SF V 4' 1.3 2 4 -37.7500 42.7500 13.0000 3 2 3 4 11 12 13
 126 'Ld R Bol-SF V 4' 1.3 2 5 -37.7500 -42.7500 13.0000 3 2 3 4 11 12 13
! Lead Truck 2D Friction wedge connection between bolster and side frame
 127 'Ld Bol-SF LL Wg' 6.8 2 4 -25.5000 39.0000 15.2500 3 2 14
 128 'Ld Bol-SF LR Wg' 6.8 2 5 -25.5000 -39.0000 15.2500 3 2 14
 129 'Ld Bol-SF TL Wg' 6.8 2 4 -42.5000 39.0000 15.2500 3 2 14
 130 'Ld Bol-SF TR Wg' 6.8 2 5 -42.5000 -39.0000 15.2500 3 2 14
! Lead Truck Vertical surface friction element for side frame to axle
! connections elements are placed +/- 3.0 inches apart to react roll, and
! pitch of the side frame
 131 'SdFm-Ax 1 L V L' 6.5 4 8  0.0000 42.0000 22.5000 3 1 2 15
```

132 'SdFm-Ax 1 L V R' 6.5 4 8 0.0000 36.0000 22.5000 3 1 2 15
133 'SdFm-Ax 1 R V R' 6.5 5 8 0.0000 -42.0000 22.5000 3 1 2 15
134 'SdFm-Ax 1 R V L' 6.5 5 8 0.0000 -36.0000 22.5000 3 1 2 15
135 'SdFm-Ax 2 L V L' 6.5 4 9 -68.0000 42.0000 22.5000 3 1 2 15
136 'SdFm-Ax 2 L V R' 6.5 4 9 -68.0000 36.0000 22.5000 3 1 2 15
137 'SdFm-Ax 2 R V R' 6.5 5 9 -68.0000 -42.0000 22.5000 3 1 2 15
138 'SdFm-Ax 2 R V L' 6.5 5 9 -68.0000 -36.0000 22.5000 3 1 2 15
! Lead Truck Vertical dampers for surface friction elements
139 'SdFm-Ax 1 L V L' 1.2 4 8 0.0000 42.0000 21.0000 3 16
140 'SdFm-Ax 1 L V R' 1.2 4 8 0.0000 36.0000 21.0000 3 16
141 'SdFm-Ax 1 R V R' 1.2 5 8 0.0000 -42.0000 21.0000 3 16
142 'SdFm-Ax 1 R V L' 1.2 5 8 0.0000 -36.0000 21.0000 3 16
143 'SdFm-Ax 2 L V L' 1.2 4 9 -68.0000 42.0000 21.0000 3 16
144 'SdFm-Ax 2 L V R' 1.2 4 9 -68.0000 36.0000 21.0000 3 16
145 'SdFm-Ax 2 R V R' 1.2 5 9 -68.0000 -42.0000 21.0000 3 16
146 'SdFm-Ax 2 R V L' 1.2 5 9 -68.0000 -36.0000 21.0000 3 16
! Lead truck side frame to axle longitudinal, lateral and yaw Stops
147 'SdFm-Ax 1 L V L' 1.1 4 8 0.0000 39.0000 21.0000 3 1 2 6 17 18 19
148 'SdFm-Ax 1 R V R' 1.1 5 8 0.0000 -39.0000 21.0000 3 1 2 6 17 18 19
149 'SdFm-Ax 2 L V L' 1.1 4 9 -68.0000 39.0000 21.0000 3 1 2 6 17 18 19
150 'SdFm-Ax 2 R V R' 1.1 5 9 -68.0000 -39.0000 21.0000 3 1 2 6 17 18 19
! Lead Truck Wheel/rail connections
151 'Ax 1 Lt Wh/Rail' 4 8 0.0000 29.7500 0.0000 1
152 'Ax 1 Rt Wh/Rail' 4 8 0.0000 -29.7500 0.0000 1
153 'Ax 2 Lt Wh/Rail' 4 9 -68.0000 29.7500 0.0000 2
154 'Ax 2 Rt Wh/Rail' 4 9 -68.0000 -29.7500 0.0000 2
155 'Dummy Ctr Plt 1' 1.1 1 2 -34.0000 0.0000 23.7500 3 4 5 6 20 20 20
! ********************** TRAILING TRUCK ********************************
! Trail Truck Lateral and longitudinal connections for 16" center plate using
! 6.2 line friction element for rim friction at four corners
201 'Tr CB-Bl LgY LL' 6.2 3 1 -573.0000 8.0000 23.7500 2 1 3
202 'Tr CB-Bl LgY LR' 6.2 1 3 -573.0000 -8.0000 23.7500 2 1 3
203 'Tr CB-Bl LtX Fr' 6.2 3 1 -565.0000 0.0000 23.7500 1 2 3

204 'Tr CB-Bl LtX Tr' 6.2 1 3 -581.0000 0.0000 23.7500 1 2 3
! Trail Truck Vertical and rotational connections for center plates using a
! surface friction element
205 'Tr CB-Bl Vt/Y F' 6.5 1 3 -565.0000 0.0000 23.7500 3 1 2 4
206 'Tr CB-Bl Vt/Y B' 6.5 1 3 -581.0000 0.0000 23.7500 3 1 2 4
207 'Tr CB-Bl Vt/X L' 6.5 1 3 -573.0000 8.0000 23.7500 3 1 2 4
208 'Tr CB-Bl Vt/X R' 6.5 1 3 -573.0000 -8.0000 23.7500 3 1 2 4
! Trail truck vertical centerplate dampers, gap connection
209 'Tr CB-Bl Vt/Y F' 1.2 1 3 -565.0000 0.0000 23.7500 3 5
210 'Tr CB-Bl Vt/Y B' 1.2 1 3 -581.0000 0.0000 23.7500 3 5
211 'Tr CB-Bl Vt/X L' 1.2 1 3 -573.0000 8.0000 23.7500 3 5
212 'Tr CB-Bl Vt/X R' 1.2 1 3 -573.0000 -8.0000 23.7500 3 5
! Trail Truck Vertical roller side bearing connections using a gap element
!213 'Tr Bol SB Lt Vt' 1.2 1 3 -548.5000 25.0000 26.5500 3 6
!214 'Tr Bol SB Rt Vt' 1.2 1 3 -548.5000 -25.0000 26.5500 3 6
! Trail Lead Truck Constant Contact Side Bearings
215 'Tr Bol SB Lt Vt' 6.2 1 3 -573.0000 25.0000 26.5500 3 1 7
216 'Tr Bol SB Rt Vt' 6.2 1 3 -573.0000 25.0000 26.5500 3 1 7
! Trail truck Long.,Pitch, and Yaw bolster to side frame connections
217 'Tr L Bol-SF LPY' 1.1 3 6 -573.0000 39.0000 15.2500 3 1 5 6 8 9 10
218 'Tr R Bol-SF LPY' 1.1 3 7 -573.0000 -39.0000 15.2500 3 1 5 6 8 9 10
! Trail Truck Vertical bolster to side frame connections
! split into 4 seperate springs at each nest, dropped down 5"
219 'Tr L Bol-SF V 1' 1.3 3 6 -569.2500 35.2500 13.0000 3 2 3 4 11 12 13
220 'Tr R Bol-SF V 1' 1.3 3 7 -569.2500 -35.2500 13.0000 3 2 3 4 11 12 13
221 'Tr L Bol-SF V 2' 1.3 3 6 -569.2500 42.7500 13.0000 3 2 3 4 11 12 13
222 'Tr R Bol-SF V 2' 1.3 3 7 -569.2500 -42.7500 13.0000 3 2 3 4 11 12 13
223 'Tr L Bol-SF V 3' 1.3 3 6 -576.7500 35.2500 13.0000 3 2 3 4 11 12 13
224 'Tr R Bol-SF V 3' 1.3 3 7 -576.7500 -35.2500 13.0000 3 2 3 4 11 12 13
225 'Tr L Bol-SF V 4' 1.3 3 6 -576.7500 42.7500 13.0000 3 2 3 4 11 12 13
226 'Tr R Bol-SF V 4' 1.3 3 7 -576.7500 -42.7500 13.0000 3 2 3 4 11 12 13
! Trail Truck 2D Friction wedge connection between bolster and side frame
227 'Tr Bol-SF LL Wg' 6.8 3 6 -564.5000 39.0000 15.2500 3 2 14

228 'Tr Bol-SF LR Wg' 6.8 3 7 -564.5000 -39.0000 15.2500 3 2 14
229 'Tr Bol-SF TL Wg' 6.8 3 6 -581.5000 39.0000 15.2500 3 2 14
230 'Tr Bol-SF TR Wg' 6.8 3 7 -581.5000 -39.0000 15.2500 3 2 14
! Trail Truck Vertical surface friction element for side frame to axle
! connections elements are placed +/- 3.0 inches apart to react roll, and
! pitch of the side frame
231 'SdFm-Ax 3 L V L' 6.5 6 10 -539.0000 42.0000 21.0000 3 1 2 15
232 'SdFm-Ax 3 L V R' 6.5 6 10 -539.0000 36.0000 21.0000 3 1 2 15
233 'SdFm-Ax 3 R V R' 6.5 7 10 -539.0000 -42.0000 21.0000 3 1 2 15
234 'SdFm-Ax 3 R V L' 6.5 7 10 -539.0000 -36.0000 21.0000 3 1 2 15
235 'SdFm-Ax 4 L V L' 6.5 6 11 -607.0000 42.0000 21.0000 3 1 2 15
236 'SdFm-Ax 4 L V R' 6.5 6 11 -607.0000 36.0000 21.0000 3 1 2 15
237 'SdFm-Ax 4 R V R' 6.5 7 11 -607.0000 -42.0000 21.0000 3 1 2 15
238 'SdFm-Ax 4 R V L' 6.5 7 11 -607.0000 -36.0000 21.0000 3 1 2 15
! Trail Truck Vertical dampers for surface friction elements
239 'SdFm-Ax 3 L V L' 1.2 6 10 -539.0000 42.0000 21.0000 3 16
240 'SdFm-Ax 3 L V R' 1.2 6 10 -539.0000 36.0000 21.0000 3 16
241 'SdFm-Ax 3 R V R' 1.2 7 10 -539.0000 -42.0000 21.0000 3 16
242 'SdFm-Ax 3 R V L' 1.2 7 10 -539.0000 -36.0000 21.0000 3 16
243 'SdFm-Ax 4 L V L' 1.2 6 11 -607.0000 42.0000 21.0000 3 16
244 'SdFm-Ax 4 L V R' 1.2 6 11 -607.0000 36.0000 21.0000 3 16
245 'SdFm-Ax 4 R V R' 1.2 7 11 -607.0000 -42.0000 21.0000 3 16
246 'SdFm-Ax 4 R V L' 1.2 7 11 -607.0000 -36.0000 21.0000 3 16
! Trail truck side frame to axle longitudinal, lateral and yaw Stops
247 'SdFm-Ax 3 L V L' 1.1 6 10 -539.0000 39.0000 21.0000 3 1 2 6 17 18 19
248 'SdFm-Ax 3 R V R' 1.1 7 10 -539.0000 -39.0000 21.0000 3 1 2 6 17 18 19
249 'SdFm-Ax 4 L V L' 1.1 6 11 -607.0000 39.0000 21.0000 3 1 2 6 17 18 19
250 'SdFm-Ax 4 R V R' 1.1 7 11 -607.0000 -39.0000 21.0000 3 1 2 6 17 18 19
! Trail Truck Wheel/rail connections
251 'Ax 3 Lt Wh/Rail' 4 10 -539.0000 29.7500 0.0000 3
252 'Ax 3 Rt Wh/Rail' 4 10 -539.0000 -29.7500 0.0000 3
253 'Ax 4 Lt Wh/Rail' 4 11 -607.0000 29.7500 0.0000 4
254 'Ax 4 Rt Wh/Rail' 4 11 -607.0000 -29.7500 0.0000 4

```
 255 'Dummy Ctr Plt 2' 1.1 1 3 -573.0000 0.0000 23.7500 3 4 5 6 20 20 20
```

For each connection characteristic, list its number, identification numbers for the piecewise linear stiffness and damping characteristics, respectively, zero if absent, and the force, moment, or stroke limits in extn and compn, (if no limit exists, set the values outside the expected range).

```
 Pair # Stiffness & Damping F/S-extn. F/S-comp. K/D-parameters
------------------------------------------------------------------------
\CHARACTERISTIC DATA
! ************************ Couplers *********************************
 1  1 0 1.00E+09 -1.00E+09
! Tow Rope
 2  2 3 1.00E+09 -1.00E+09
! ********************* Center Plate ********************************
! Center plate longitudinal and lateral rim friction
 3  4 0 1.00E+00 -1.00E+00 0.00E+00 1.00E+06 1.00E+03 5.00E-01
! Centerplate vertical with longitudinal and lateral surface friction
!
! Cw = Car weight
! Mu1  friction value for the center plate
! Mu2 effective friction value for this simulation
! R= radius of center plate
!
! Charct. #5 The normal formula for calculating the center plate breakout
! torque for one bowl is (Cw*Mu1*R)/3. This model assumes all loads are
! carried at the lateral edges of the center plate. This produces a breakout
! torque equal to (Mu2*Cw*R)/4 for each edge. Setting the two equations
! equal to each other produces the effective Mu, R relationship. Therefore,
! Mu1*2/3 = Mu2.
! Center Plate Lube 0.1 2/3*.1 = 0.0666
! Center Plate Lube 0.2 2/3*.2 = 0.1333
! Center Plate Lube 0.3 2/3*.3 = 0.2000
```

```
! Center Plate Lube 0.4 2/3*.4 = 0.2666
! Center Plate Lube 0.5 2/3*.5 = 0.3333
! 4 5   0  1.0E06 1.0E03 0.0666
! 4 5   0  1.0E06 1.0E03 0.3333
 4  5 0       1.00E+06 1.00E+03 2.67E-01
! Centerplate damping, type 1.2 connection
 5  0 6 1.00E+03 1.95E-03
!
! ********************* Roller Side Bearings *******************************
! Gap element at for roller side bearings, -0.250 accounts for deflection of
! center plate springs.
! 6  7 8 1.00E+03 -2.50E-01
! ********************* Constant Contact Side Bearings *********************
 7  9 10 3.00E+00 -3.00E+00 0.00E+00 1.00E+06 1.00E+03 3.00E-01
! ********************* Bolster to Side Frame Connections ******************
! Longitudinal
 8 11 12 1.00E+09 -1.00E+09
! Pitch stiffness and stops
 9 13 0 1.00E+09 -1.00E+09
! Warp/torsion
 10 14 0 1.00E+09 -1.00E+09
! Lateral stiffness and stops
 11 15 0 1.00E+09 -1.00E+09
! Vertical Springs
 12 16 0 0.00E+00 -1.00E+09
! Dummy roll characteristic for type 1.3 connection
 13  0 0 1.00E+09 -1.00E+09
! # 4 is a 6.3 wedge element with pwl numbers, wedge angle, force, LVB,
! and friction, Constant damped truck is 1979 lb/in in the control coils
! at zero wedge rise the control coils are compressed 1.8393 inches
! 0.0 inch wedge rise
! Ch # Pwl Stiff Pwl Damp Wedge Angle Force LB  Mu
! 14  0   0  37.5  3.640E03 1.0E04 0.40
```

```
! 0.25 inch wedge rise (1.8393 - 0.25 = 1.5893 * 1979 = 3145)
! Ch # Pwl Stiff Pwl Damp Wedge Angle Force LB  Mu
! 14  0   0  37.5  3.1450E03 1.0E04 0.40
! 0.375 inch wedge rise (1.8393 -.375=1.4643*1979=2898)
! Ch # Pwl Stiff Pwl Damp Wedge Angle Force LB  Mu
! 14  0   0  37.5  2.898E03 1.0E04 0.40
! modified for new type 6.7, MU1 for slope Mu2 for Face, T=Toe out, F=Toe in
! Ch # Pwl Stf Pwl Damp Wedge Ang Force LB  Mu1 Mu2 Toe
! 14  0 0 3.75E+01 2.90E+03 1.00E+04 4.00E-01 4.00E-01 .T.
! 0.50 inch wedge rise (1.8393 - 0.50 = 1.3393 * 1979 = 2650)
! Ch # Pwl Stiff Pwl Damp Wedge Angle Force LB  Mu
! 14  0   0  37.5  2.650E03 1.0E04 0.40
! 0.75 inch wedge rise (1.8393 - 0.75 = 1.0893 * 1979 = 2155)
! Ch # Pwl Stiff Pwl Damp Wedge Angle Force LB  Mu
! 14  0 0 3.75E+01 2.16E+03 1.00E+04 4.00E-01 0.00E+00
!
! Option for a VARIABLE DAMPED TRUCK design
! Ch # Pwl Stf Pwl Damp Wedge Ang Force LB  Mu1 Mu2 Toe
! 14  17   0  32.0  0.0 1.0E04 0.40 0.40 .T.
! 6.8 Wedge
! Ch # Pwl Stiff PwlDamp Wedge Angle Force  C1  C2  Mu Face Mu Back Toe Long K
 14  0   0  37.5  3.640E03 1.0E6 1.0E3 0.40  0.40 .T. 1.0E5
! 14 17   0  37.5  0.0  1.0E6 1.0E3 0.32  0.32 .T. 1.0E5
!****************** Bearing Adapter Side Frame to Axle ********************
! Vertical side frame to axle connections with friction, type 6.5
 15 18 0        1.00E+06 1.00E+03 0.50
! Vertical damping for bearing adapters with gap element
 16  0 19 1.00E+03 1.13E-02
! Longitudinal stiffness and stops
 17 20 0 1.00E+09 -1.00E+09
! Lateral stiffness and stops
 18 21 0 1.00E+09 -1.00E+09
! Yaw stiffness and stops
```

```
 19 22 0 1.00E+09 -1.00E+09
! Dummy Center Plate Roll/Pitch/Yaw Connection
 20  0 0 1.00E+09 -1.00E+09
```

For type 4 - axle to track characteristics, give a lateral stiffness and
damping and identification numbers for the vertical PWL stiffness and damping,
then for each, list an identification number, the nominal wheel radius, WRAD,
a wheel rotation index, INDWH, .F. for solid, .T. for independent wheels,
traction torque input nos., ITRQ, for left and right wheels, 0 for none, and,
for independent wheels, KWHL, DWHL, the axle torsional stiffness and damping.

```
 Axle #  WRAD  INDWH  ITRQ-L ITRQ-R  KWHL  DWHL
--------------------------------------------------------------------------
$\WHEEL/RAIL ELEMENT TIE
$ 1.000E+05 1.000E+02 1.000E+05 1.000E+02 2.500E+05 2.500E+02
\WHEEL/RAIL ELEMENT
 1.000E+05 1.000E+02 2.500E+05 2.500E+02
 1  16.500  .F.   0   0
 2  16.500  .F.   0   0
 3  16.500  .F.   0   0
 4  16.500  .F.   0   0
```

For each piecewise linear function, list the identification number, the number
of break points, and the ordinate, lb or in-lb, over abscissa, inches or rad,
at each break point.

Note - extension is assumed to be positive for both ordinate and abscissa and
  0.0 for the first break point indicates symmetry about the origin.

```
 PWL IBP Ordinates over Abscissae
--------------------------------------------------------------------------
\PWL DATA
! ************************ Couplers **********************************
```

```
! Coupler to Ground Lead and Trail Ends
 1 2 0.0000E+00 1.0000E+01
   0.000000 1.000000
! Tow Rope to Ground Through C.G.
! 1500 LB/IN
 2 2 0.0000E+00 1.5000E+03
   0.000000 1.000000
 3 2 0.0000E+00 1.5000E+02
   0.000000 1.000000
! ********************* Center plate Connections *************************
! Longitudinal and lateral rim normal stiffness
! Steel on steel, with 80 lb/in +/-0.125 inch gap
 4 4 -1.1010E+03 -1.0000E+01 0.0000E+00 0.0000E+00
   -0.126000 -0.125000 0.000000 1.000000
! Vertical lift off spring for center plate
! The center plate stiffness has been increased from 1xE6 to 1xE7 to
! improve the roll calculation.
! with initial offsets
!
!Empty
! 5 3 -2.9570E+03 0.0000E+00 0.0000E+00
!   0.000000 0.0002957 1.000000
! Loaded
 5 3 -1.9530E+04 0.0000E+00 0.0000E+00
   0.000000 0.001953 1.000000
! Damping of center plate
 6 2 0.0000E+00 1.0000E+03
   0.000000 1.000000
! ********************* Roller Side Bearings ******************************
! Lift off spring for side bearings
! 7 3 -1.0000E+06 0.0000E+00 0.0000E+00
!   -1.000000 0.000000 1.000000
! Damping of side bearings
```

```
! 8 2 0.0000E+00 0.0000E+00
!   0.000000 1.000000
! ********************* Constant Contact Side Bearings *********************
! TCC-III-45 Long Travels
 9 7 -8.8000E+03 -7.8000E+03 -5.8000E+03 -4.3000E+03 -1.8000E+03 0.0000E+00
0.0000E+00
   -0.626000 -0.625000 -0.312500 0.000000 0.500000 1.000000 2.000000
! CCSB Damping
 10 3 0.0000E+00 1.0000E+03 1.0000E+03
   0.000000 0.050000 1.000000
! ********************* Bolster to Side Frame Connections *******************
! Longitudinal
 11 2 0.0000E+00 1.0000E+06
   0.000000 1.000000
 12 2 0.0000E+00 1.0000E+03
   0.000000 1.000000
! Pitch Stiffness and Stops Mid Tolerance is Approx +/- 2.4 Degrees=0.042mRad
 13 3 0.0000E+00 0.0000E+00 6.4000E+07
   0.000000 0.042000 1.042000
! ****************** Warp resistance ************************************
! worn truck
! Warp resistance for bolster to side frame
! 14  3  0.0  5.25E04 6.924E05
!     0.0  0.030  0.040
! New truck
! Warp resistance for bolster to side frame
 14 3 0.0000E+00 2.5500E+05 8.9500E+05
   0.000000 0.030000 0.040000
! Stiff H-frame truck
! Warp resistance for bolster to side frame
! 14  3  0.0  1.275E06 1.915E06
!     0.0  0.030  0.040
! ******************************** Empty *****************************
```

! LATERAL STIFFNESS OF BOLSTER TO SIDE FRAME CONNECTION FOR ONE OF 4 EFFECTIVE SPRINGS in pounds and inches

! 15 3 0.000E+0 1.281E+3 1.013E+5

!   0.0000 0.5000 0.6000

! VERTICAL SUSPENSION WITH STATIC DEFLECTIONS FOR 4 EQUIVALENT SPRINGS

! 7-D5 OUTER 6-D5 INNER SPRINGS

! IN LBS AND INCHES

! 16 6 -4.577E+4 -2.077E+4 -2.775E+3 -1.050E+2 0.000E+0 0.000E+0

!   -3.3110 -3.2110 0.0000 0.4765 0.5390 1.5390

! ******************************** Loaded ******************************

! LATERAL STIFFNESS OF BOLSTER TO SIDE FRAME CONNECTION FOR ONE OF 4 EFFECTIVE SPRINGS in pounds and inches

! 7-D5 OUTER 6-D5 INNER SPRINGS

 15 3 0.000E+0 1.650E+3 1.017E+5

   0.0000 0.5000 0.6000

! VERTICAL SUSPENSION WITH STATIC DEFLECTIONS FOR 4 EQUIVALENT SPRINGS

! 7-D5 OUTER 6-D5 INNER SPRINGS

! IN LBS AND INCHES

 16 6 -4.577E+4 -2.077E+4 -1.106E+4 -1.050E+2 0.000E+0 0.000E+0

   -1.8323 -1.7323 0.0000 1.9552 2.0177 3.0177

!****************** Bearing Adapter Side Frame to Axle ********************

! Vertical Bearing adapter connection with offset for static load

!

!Empty

!18 3 -3.3225E+03 0.0000E+00 0.0000E+00

!   0.000000 0.003032 1.000000

! Loaded

 18 3 -1.1318E+04 0.0000E+00 0.0000E+00

   0.000000 0.011318 1.000000

! Vertical Bearing adapter damping

 19 2 0.0000E+00 1.0000E+03

   0.000000 1.000000

! Bearing adapter stops

! Longitudinal Stiffness with Stops

```
 20 3 0.0000E+00 1.0000E+00 1.0000E+03
   0.000000 0.046800 0.047800
```

! Lateral Stiffness with Stops

```
 21 3 0.0000E+00 1.0000E+00 1.0000E+03
   0.000000 0.250000 0.251000
```

! Yaw Stiffness with Stops

```
 22 3 0.0000E+00 0.0000E+00 6.4000E+05
   0.000000 0.030000 0.040000
```

Loaded Hopper Car

System file (.SYS) for NUCARS Version 2014

===

\SYSTEM TITLE

Loaded 110T Hopper Car w/CCSB LT w/optional Roller Side Bearings

Give the number of bodies, then for each, list the number, name, up to 15 characters in single quotes, and c.g. position, relative to a chosen datum, followed by the number and list of degrees of freedom required (from 1=x, 2=y, 3=z, 4=phi, 5=theta, 6=psi, 7=epsx, 8=epsy, 9=epsz), and the mass and inertias in roll, pitch, and yaw. The degrees of freedom required for each axle are 2, 3, 4, and 6. A longitudinal degree of freedom, 1, is optional.

```
 Body # ' 15 Char Name '   C.G. Posn in X, Y, & Z
           No. & DoF List   Mass, Roll, Pitch, & Yaw Inertia
------------------------------------------------------------------------
\BODY DATA
 11
! 110-Ton Loaded Body
 1 ' Full Main Body'  -280.0000  0.0000  85.0000
 6 1 2 3 4 5 6    683.360 1993579 18094645 18094645
!100-ton car
!  1 ' Full Main Body'   -278.0  0.0  83.0
!          6 1 2 3 4 5 6 630.79 1.84E06 1.67E07 1.67E07
!110-ton trucks
 2 'Leading Bolster'   -36.0000  0.0000  16.2500
 6 1 2 3 4 5 6      4.1960 3.0850E+03 2.5200E+02 3.0850E+03
 3 'Trailng Bolster'  -522.0000  0.0000  16.2500
 6 1 2 3 4 5 6      4.1960 3.0850E+03 2.5200E+02 3.0850E+03
 4 'Lead Lft Sframe'   -36.0000 39.5000  18.0000
 6 1 2 3 4 5 6      3.1800 9.1000E+02 1.7045E+03 1.5620E+03
 5 'Lead Rgt Sframe'   -36.0000 -39.5000  18.0000
 6 1 2 3 4 5 6      3.1800 9.1000E+02 1.7045E+03 1.5620E+03
 6 'Trail Lt Sframe'  -522.0000 39.5000  18.0000
 6 1 2 3 4 5 6      3.1800 9.1000E+02 1.7045E+03 1.5620E+03
 7 'Trail Rt Sframe'  -522.0000 -39.5000  18.0000
 6 1 2 3 4 5 6      3.1800 9.1000E+02 1.7045E+03 1.5620E+03
```

```
 8 ' Axle number 1 '   0.0000  0.0000  18.0000
 5 1 2 3 4 6      9.0720 8.6840E+03 2.1510E+03 8.6840E+03
 9 ' Axle number 2 '   -72.0000  0.0000  18.0000
 5 1 2 3 4 6      9.0720 8.6840E+03 2.1510E+03 8.6840E+03
 10 ' Axle number 3 '  -486.0000  0.0000  18.0000
 5 1 2 3 4 6      9.0720 8.6840E+03 2.1510E+03 8.6840E+03
 11 ' Axle number 4 '  -558.0000  0.0000  18.0000
 5 1 2 3 4 6      9.0720 8.6840E+03 2.1510E+03 8.6840E+03

\CONNECTION DATA
 109
! Location of Couplers to Ground, Set to 1E1 lb/in
 1 'Coupler to Grnd' 1 1 0  36.0000 0.0000 31.5000 1 1
 2 'Coupler to Grnd' 1 1 0 -594.0000 0.0000 31.5000 1 1
! Tow Rope to Ground through C.G. location on the Car Body
 3 'Tow Rope - Grnd' 1 1 0 -279.0000 0.0000 85.0000 1 2
! ********************** LEADING TRUCK ********************************
! Lead Truck Lateral and longitudinal connections for 16" center plate using
! 6.2 line friction element for rim friction at four corners
 101 'Ld CB-Bl LgY LL' 6.2 2 1 -36.0000 8.0000 23.2500 2 1 3
 102 'Ld CB-Bl LgY LR' 6.2 1 2 -36.0000 -8.0000 23.2500 2 1 3
 103 'Ld CB-Bl LtX Fr' 6.2 2 1 -28.0000 0.0000 23.2500 1 2 3
 104 'Ld CB-Bl LtX Tr' 6.2 1 2 -44.0000 0.0000 23.2500 1 2 3
! Lead Truck Vertical and rotational connections for center plates using a
! surface friction element
 105 'Ld CB-Bl Vt/Y F' 6.5 1 2 -28.0000 0.0000 23.2500 3 1 2 4
 106 'Ld CB-Bl Vt/Y B' 6.5 1 2 -44.0000 0.0000 23.2500 3 1 2 4
 107 'Ld CB-Bl Vt/X L' 6.5 1 2 -36.0000 8.0000 23.2500 3 1 2 4
 108 'Ld CB-Bl Vt/X R' 6.5 1 2 -36.0000 -8.0000 23.2500 3 1 2 4
! Lead truck vertical centerplate dampers, gap connection
 109 'Ld CB-Bl Vt/Y F' 1.2 1 2 -28.0000 0.0000 23.2500 3 5
 110 'Ld CB-Bl Vt/Y B' 1.2 1 2 -44.0000 0.0000 23.2500 3 5
 111 'Ld CB-Bl Vt/X L' 1.2 1 2 -36.0000 8.0000 23.2500 3 5
```

112 'Ld CB-Bl Vt/X R' 1.2 1 2 -36.0000 -8.0000 23.2500 3 5
! Lead Truck Vertical roller side bearing connections using a gap element
!113 'Ld Bol SB Lt Vt' 1.2 1 2 -36.0000 25.0000 28.2500 3 6
!114 'Ld Bol SB Rt Vt' 1.2 1 2 -36.0000 -25.0000 28.2500 3 6
! Lead Truck Constant Contact Side Bearings
115 'Ld Bol SB Lt Vt' 6.2 1 2 -36.0000 25.0000 28.2500 3 1 7
116 'Ld Bol SB Rt Vt' 6.2 1 2 -36.0000 -25.0000 28.2500 3 1 7
! Lead truck Long.,Pitch, and Yaw bolster to side frame connections
117 'Ld L Bol-SF LPY' 1.1 2 4 -36.0000 39.5000 16.2500 3 1 5 6 8 9 10
118 'Ld R Bol-SF LPY' 1.1 2 5 -36.0000 -39.5000 16.2500 3 1 5 6 8 9 10
! Lead Truck Vertical bolster to side frame connections
! split into 4 seperate springs at each nest, dropped down 5"
119 'Ld L Bol-SF V 1' 1.3 2 4 -32.2500 35.7500 13.0000 3 2 3 4 11 12 13
120 'Ld R Bol-SF V 1' 1.3 2 5 -32.2500 -35.7500 13.0000 3 2 3 4 11 12 13
121 'Ld L Bol-SF V 2' 1.3 2 4 -32.2500 43.2500 13.0000 3 2 3 4 11 12 13
122 'Ld R Bol-SF V 2' 1.3 2 5 -32.2500 -43.2500 13.0000 3 2 3 4 11 12 13
123 'Ld L Bol-SF V 3' 1.3 2 4 -39.7500 35.7500 13.0000 3 2 3 4 11 12 13
124 'Ld R Bol-SF V 3' 1.3 2 5 -39.7500 -35.7500 13.0000 3 2 3 4 11 12 13
125 'Ld L Bol-SF V 4' 1.3 2 4 -39.7500 43.2500 13.0000 3 2 3 4 11 12 13
126 'Ld R Bol-SF V 4' 1.3 2 5 -39.7500 -43.2500 13.0000 3 2 3 4 11 12 13
! Lead Truck 2D Friction wedge connection between bolster and side frame
127 'Ld Bol-SF LL Wg' 6.8 2 4 -27.5000 39.5000 16.2500 3 2 14
128 'Ld Bol-SF LR Wg' 6.8 2 5 -27.5000 -39.5000 16.2500 3 2 14
129 'Ld Bol-SF TL Wg' 6.8 2 4 -44.5000 39.5000 16.2500 3 2 14
130 'Ld Bol-SF TR Wg' 6.8 2 5 -44.5000 -39.5000 16.2500 3 2 14
! Lead Truck Vertical surface friction element for side frame to axle
! connections elements are placed +/- 3.0 inches apart to react roll, and
! pitch of the side frame
131 'SdFm-Ax 1 L V L' 6.5 4 8 0.0000 42.5000 22.5000 3 1 2 15
132 'SdFm-Ax 1 L V R' 6.5 4 8 0.0000 36.5000 22.5000 3 1 2 15
133 'SdFm-Ax 1 R V R' 6.5 5 8 0.0000 -42.5000 22.5000 3 1 2 15
134 'SdFm-Ax 1 R V L' 6.5 5 8 0.0000 -36.5000 22.5000 3 1 2 15
135 'SdFm-Ax 2 L V L' 6.5 4 9 -72.0000 42.5000 22.5000 3 1 2 15

136 'SdFm-Ax 2 L V R' 6.5 4 9 -72.0000 36.5000 22.5000 3 1 2 15

137 'SdFm-Ax 2 R V R' 6.5 5 9 -72.0000 -42.5000 22.5000 3 1 2 15

138 'SdFm-Ax 2 R V L' 6.5 5 9 -72.0000 -36.5000 22.5000 3 1 2 15

! Lead Truck Vertical dampers for surface friction elements

139 'SdFm-Ax 1 L V L' 1.2 4 8 0.0000 42.5000 22.5000 3 16

140 'SdFm-Ax 1 L V R' 1.2 4 8 0.0000 36.5000 22.5000 3 16

141 'SdFm-Ax 1 R V R' 1.2 5 8 0.0000 -42.5000 22.5000 3 16

142 'SdFm-Ax 1 R V L' 1.2 5 8 0.0000 -36.5000 22.5000 3 16

143 'SdFm-Ax 2 L V L' 1.2 4 9 -72.0000 42.5000 22.5000 3 16

144 'SdFm-Ax 2 L V R' 1.2 4 9 -72.0000 36.5000 22.5000 3 16

145 'SdFm-Ax 2 R V R' 1.2 5 9 -72.0000 -42.5000 22.5000 3 16

146 'SdFm-Ax 2 R V L' 1.2 5 9 -72.0000 -36.5000 22.5000 3 16

! Lead truck side frame to axle longitudinal, lateral and yaw Stops

147 'SdFm-Ax 1 L V L' 1.1 4 8 0.0000 39.5000 22.5000 3 1 2 6 17 18 19

148 'SdFm-Ax 1 R V R' 1.1 5 8 0.0000 -39.5000 22.5000 3 1 2 6 17 18 19

149 'SdFm-Ax 2 L V L' 1.1 4 9 -72.0000 39.5000 22.5000 3 1 2 6 17 18 19

150 'SdFm-Ax 2 R V R' 1.1 5 9 -72.0000 -39.5000 22.5000 3 1 2 6 17 18 19

! Lead Truck Wheel/rail connections

151 'Ax 1 Lt Wh/Rail' 4 8 0.0000 29.7500 0.0000 1

152 'Ax 1 Rt Wh/Rail' 4 8 0.0000 -29.7500 0.0000 1

153 'Ax 2 Lt Wh/Rail' 4 9 -72.0000 29.7500 0.0000 2

154 'Ax 2 Rt Wh/Rail' 4 9 -72.0000 -29.7500 0.0000 2

155 'Dummy Ctr Plt 1' 1.1 1 2 -36.0000 0.0000 23.2500 3 4 5 6 20 20 20

! ********************** TRAILING TRUCK ********************************

! Trail Truck Lateral and longitudinal connections for 16" center plate using

! 6.2 line friction element for rim friction at four corners

201 'Tr CB-Bl LgY LL' 6.2 3 1 -522.0000 8.0000 23.2500 2 1 3

202 'Tr CB-Bl LgY LR' 6.2 1 3 -522.0000 -8.0000 23.2500 2 1 3

203 'Tr CB-Bl LtX Fr' 6.2 3 1 -514.0000 0.0000 23.2500 1 2 3

204 'Tr CB-Bl LtX Tr' 6.2 1 3 -530.0000 0.0000 23.2500 1 2 3

! Trail Truck Vertical and rotational connections for center plates using a

! surface friction element

205 'Tr CB-Bl Vt/Y F' 6.5 1 3 -514.0000 0.0000 23.2500 3 1 2 4

```
 206 'Tr CB-Bl Vt/Y B' 6.5 1 3 -530.0000 0.0000 23.2500 3 1 2 4
 207 'Tr CB-Bl Vt/X L' 6.5 1 3 -522.0000 8.0000 23.2500 3 1 2 4
 208 'Tr CB-Bl Vt/X R' 6.5 1 3 -522.0000 -8.0000 23.2500 3 1 2 4
! Trail truck vertical centerplate dampers, gap connection
 209 'Tr CB-Bl Vt/Y F' 1.2 1 3 -514.0000 0.0000 23.2500 3 5
 210 'Tr CB-Bl Vt/Y B' 1.2 1 3 -530.0000 0.0000 23.2500 3 5
 211 'Tr CB-Bl Vt/X L' 1.2 1 3 -522.0000 8.0000 23.2500 3 5
 212 'Tr CB-Bl Vt/X R' 1.2 1 3 -522.0000 -8.0000 23.2500 3 5
! Trail Truck Vertical roller side bearing connections using a gap element
!213 'Tr Bol SB Lt Vt' 1.2 1 3 -521.0000 25.000 28.2500 3 6
!214 'Tr Bol SB Rt Vt' 1.2 1 3 -521.0000 -25.000 28.2500 3 6
! Trail Lead Truck Constant Contact Side Bearings
 215 'Tr Bol SB Lt Vt' 6.2 1 3 -522.0000 25.0000 28.2500 3 1 7
 216 'Tr Bol SB Rt Vt' 6.2 1 3 -522.0000 -25.0000 28.2500 3 1 7
! Trail truck Long.,Pitch, and Yaw bolster to side frame connections
 217 'Tr L Bol-SF LPY' 1.1 3 6 -522.0000 39.5000 16.2500 3 1 5 6 8 9 10
 218 'Tr R Bol-SF LPY' 1.1 3 7 -522.0000 -39.5000 16.2500 3 1 5 6 8 9 10
! Trail Truck Vertical bolster to side frame connections
! split into 4 seperate springs at each nest, dropped down 5"
 219 'Tr L Bol-SF V 1' 1.3 3 6 -518.2500 35.7500 13.0000 3 2 3 4 11 12 13
 220 'Tr R Bol-SF V 1' 1.3 3 7 -518.2500 -35.7500 13.0000 3 2 3 4 11 12 13
 221 'Tr L Bol-SF V 2' 1.3 3 6 -518.2500 43.2500 13.0000 3 2 3 4 11 12 13
 222 'Tr R Bol-SF V 2' 1.3 3 7 -518.2500 -43.2500 13.0000 3 2 3 4 11 12 13
 223 'Tr L Bol-SF V 3' 1.3 3 6 -525.7500 35.7500 13.0000 3 2 3 4 11 12 13
 224 'Tr R Bol-SF V 3' 1.3 3 7 -525.7500 -35.7500 13.0000 3 2 3 4 11 12 13
 225 'Tr L Bol-SF V 4' 1.3 3 6 -525.7500 43.2500 13.0000 3 2 3 4 11 12 13
 226 'Tr R Bol-SF V 4' 1.3 3 7 -525.7500 -43.2500 13.0000 3 2 3 4 11 12 13
! Trail Truck 2D Friction wedge connection between bolster and side frame
 227 'Tr Bol-SF LL Wg' 6.8 3 6 -513.5000 39.5000 16.2500 3 2 14
 228 'Tr Bol-SF LR Wg' 6.8 3 7 -513.5000 -39.5000 16.2500 3 2 14
 229 'Tr Bol-SF TL Wg' 6.8 3 6 -530.5000 39.5000 16.2500 3 2 14
 230 'Tr Bol-SF TR Wg' 6.8 3 7 -530.5000 -39.5000 16.2500 3 2 14
! Trail Truck Vertical surface friction element for side frame to axle
```

! connections elements are placed +/- 3.0 inches apart to react roll, and
! pitch of the side frame
231 'SdFm-Ax 3 L V L' 6.5 6 10 -486.0000 42.5000 22.5000 3 1 2 15
232 'SdFm-Ax 3 L V R' 6.5 6 10 -486.0000 36.5000 22.5000 3 1 2 15
233 'SdFm-Ax 3 R V R' 6.5 7 10 -486.0000 -42.5000 22.5000 3 1 2 15
234 'SdFm-Ax 3 R V L' 6.5 7 10 -486.0000 -36.5000 22.5000 3 1 2 15
235 'SdFm-Ax 4 L V L' 6.5 6 11 -558.0000 42.5000 22.5000 3 1 2 15
236 'SdFm-Ax 4 L V R' 6.5 6 11 -558.0000 36.5000 22.5000 3 1 2 15
237 'SdFm-Ax 4 R V R' 6.5 7 11 -558.0000 -42.5000 22.5000 3 1 2 15
238 'SdFm-Ax 4 R V L' 6.5 7 11 -558.0000 -36.5000 22.5000 3 1 2 15
! Trail Truck Vertical dampers for surface friction elements
239 'SdFm-Ax 3 L V L' 1.2 6 10 -486.0000 42.5000 22.5000 3 16
240 'SdFm-Ax 3 L V R' 1.2 6 10 -486.0000 36.5000 22.5000 3 16
241 'SdFm-Ax 3 R V R' 1.2 7 10 -486.0000 -42.5000 22.5000 3 16
242 'SdFm-Ax 3 R V L' 1.2 7 10 -486.0000 -36.5000 22.5000 3 16
243 'SdFm-Ax 4 L V L' 1.2 6 11 -558.0000 42.5000 22.5000 3 16
244 'SdFm-Ax 4 L V R' 1.2 6 11 -558.0000 36.5000 22.5000 3 16
245 'SdFm-Ax 4 R V R' 1.2 7 11 -558.0000 -42.5000 22.5000 3 16
246 'SdFm-Ax 4 R V L' 1.2 7 11 -558.0000 -36.5000 22.5000 3 16
! Trail truck side frame to axle longitudinal, lateral and yaw Stops
247 'SdFm-Ax 3 L V L' 1.1 6 10 -486.0000 39.5000 22.5000 3 1 2 6 17 18 19
248 'SdFm-Ax 3 R V R' 1.1 7 10 -486.0000 -39.5000 22.5000 3 1 2 6 17 18 19
249 'SdFm-Ax 4 L V L' 1.1 6 11 -558.0000 39.5000 22.5000 3 1 2 6 17 18 19
250 'SdFm-Ax 4 R V R' 1.1 7 11 -558.0000 -39.5000 22.5000 3 1 2 6 17 18 19
! Trail Truck Wheel/rail connections
251 'Ax 3 Lt Wh/Rail' 4 10 -486.0000 29.7500 0.0000 3
252 'Ax 3 Rt Wh/Rail' 4 10 -486.0000 -29.7500 0.0000 3
253 'Ax 4 Lt Wh/Rail' 4 11 -558.0000 29.7500 0.0000 4
254 'Ax 4 Rt Wh/Rail' 4 11 -558.0000 -29.7500 0.0000 4
255 'Dummy Ctr Plt 2' 1.1 1 3 -522.0000 0.0000 23.2500 3 4 5 6 20 20 20

For each connection characteristic, list its number, identification numbers for the piecewise linear stiffness and damping characteristics, respectively,

zero if absent, and the force, moment, or stroke limits in extn and compn,
(if no limit exists, set the values outside the expected range).

```
 Pair # Stiffness & Damping F/S-extn. F/S-comp. K/D-parameters
--------------------------------------------------------------------------
\CHARACTERISTIC DATA
! ************************* Couplers ***********************************
 1  1 0 1.00E+09 -1.00E+09
! Tow Rope
 2  2 3 1.00E+09 -1.00E+09
! ********************** Center Plate **********************************
! Center plate longitudinal and lateral rim friction
 3  4 0 1.00E+00 -1.00E+00 0.00E+00 1.00E+06 1.00E+03 5.00E-01
! Centerplate vertical with longitudinal and lateral surface friction
!
! Cw = Car weight
! Mu1 friction value for the center plate
! Mu2 effective friction value for this simulation
! R= radius of center plate
!
! Charct. #5 The normal formula for calculating the center plate breakout
! torque for one bowl is (Cw*Mu1*R)/3. This model assumes all loads are
! carried at the lateral edges of the center plate. This produces a breakout
! torque equal to (Mu2*Cw*R)/4 for each edge. Setting the two equations
! equal to each other produces the effective Mu, R relationship. Therefore,
! Mu1*2/3 = Mu2.
! Center Plate Lube 0.1 2/3*.1 = 0.0666
! Center Plate Lube 0.2 2/3*.2 = 0.1333
! Center Plate Lube 0.3 2/3*.3 = 0.2000
! Center Plate Lube 0.4 2/3*.4 = 0.2666
! Center Plate Lube 0.5 2/3*.5 = 0.3333
! 4 5   0  1.0E06 1.0E03 0.0666
! 4 5   0  1.0E06 1.0E03 0.3333
```

```
 4  5 0       1.00E+06 1.00E+03 2.67E-01
! Centerplate damping, type 1.2 connection
 5  0 6 1.00E+03 3.04E-03
! ********************* Roller Side Bearings ********************************
! Gap element at for roller side bearings, -0.250 accounts for deflection of
! center plate springs.
! 6 7   8  1000.0  -0.250
! ********************* Constant Contact Side Bearings *********************
 7  9 10 3.00E+00 -3.00E+00 0.00E+00 1.00E+06 1.00E+03 3.00E-01
! ********************* Bolster to Side Frame Connections ******************
! Longitudinal
 8 11 12 1.00E+09 -1.00E+09
! Pitch stiffness and stops
 9 13 0 1.00E+09 -1.00E+09
! Warp/torsion
 10 14 0 1.00E+09 -1.00E+09
! Lateral stiffness and stops
 11 15 0 1.00E+09 -1.00E+09
! Vertical Springs
 12 16 0 0.00E+00 -1.00E+09
! Dummy roll characteristic for type 1.3 connection
 13  0 0 1.00E+09 -1.00E+09
! # 4 is a 6.3 wedge element with pwl numbers, wedge angle, force, LVB,
! and friction, Constant damped truck is 1979 lb/in in the control coils
! at zero wedge rise the control coils are compressed 1.8393 inches
! 0.0 inch wedge rise
! Ch # Pwl Stiff Pwl Damp Wedge Angle Force LB  Mu
! 14  0   0  37.5  3.640E03 1.0E04 0.40
! 0.25 inch wedge rise (1.8393 - 0.25 = 1.5893 * 1979 = 3145)
! Ch # Pwl Stiff Pwl Damp Wedge Angle Force LB  Mu
! 14  0   0  37.5  3.1450E03 1.0E04 0.40
! 0.375 inch wedge rise (1.8393 -.375=1.4643*1979=2898)
! Ch # Pwl Stiff Pwl Damp Wedge Angle Force LB  Mu
```

```
! 14  0 0 3.75E+01 2.90E+03 1.00E+04 4.00E-01 0.00E+00
! modified for new type 6.7, MU1 for slope Mu2 for Face, T=Toe out, F=Toe in
! Ch # Pwl Stf Pwl Damp Wedge Ang Force LB  Mu1 Mu2 Toe
! 14  0   0  37.5 2.898E3 1.0E04 0.40 0.40 .T.
! 0.50 inch wedge rise (1.8393 - 0.50 = 1.3393 * 1979 = 2650)
! Ch # Pwl Stiff Pwl Damp Wedge Angle Force LB  Mu
! 14  0   0  37.5  2.650E03 1.0E04 0.40
! 0.75 inch wedge rise (1.8393 - 0.75 = 1.0893 * 1979 = 2155)
! Ch # Pwl Stiff Pwl Damp Wedge Angle Force LB  Mu
! 14  0   0  37.5  2.155E03 1.0E04 0.40
! Option for a VARIABLE DAMPED TRUCK design
! Ch # Pwl Stf Pwl Damp Wedge Ang Force LB  Mu1 Mu2 Toe
! 14  17   0  32.0  0.0 1.0E04 0.40 0.40 .T.
! Ch # Pwl Stiff PwlDamp Wedge Angle Force  C1  C2  Mu Face Mu Back Toe Long K
 14 17   0  35.0  0.0 1.0E6 1.0E3 0.32  0.32 .T. 1.0E5
!****************** Bearing Adapter Side Frame to Axle ********************
! Vertical side frame to axle connections with friction, type 6.5
 15 18 0        1.00E+06 1.00E+03 5.00E-01
! Vertical damping for bearing adapters with gap element
 16  0 19 1.00E+03 3.14E-02
! Longitudinal stiffness and stops
 17 20 0 1.00E+09 -1.00E+09
! Lateral stiffness and stops
 18 21 0 1.00E+09 -1.00E+09
! Yaw stiffness and stops
 19 22 0 1.00E+09 -1.00E+09
! Dummy Center Plate Roll/Pitch/Yaw Connection
 20  0 0 1.00E+09 -1.00E+09
```

For type 4 - axle to track characteristics, give a lateral stiffness and damping and identification numbers for the vertical PWL stiffness and damping, then for each, list an identification number, the nominal wheel radius, WRAD, a wheel rotation index, INDWH, .F. for solid, .T. for independent wheels,

traction torque input nos., ITRQ, for left and right wheels, 0 for none, and,
for independent wheels, KWHL, DWHL, the axle torsional stiffness and damping.

```
 Axle #  WRAD  INDWH  ITRQ-L ITRQ-R  KWHL  DWHL
------------------------------------------------------------------------
$\WHEEL/RAIL ELEMENT TIE
$ 1.000E+05 1.000E+02 1.000E+05 1.000E+02 2.500E+05 2.500E+02
\WHEEL/RAIL ELEMENT
 1.E5 1.E2 2.5E5 2.5E2
 1  18.000  .F.   0   0
 2  18.000  .F.   0   0
 3  18.000  .F.   0   0
 4  18.000  .F.   0   0
```

For each piecewise linear function, list the identification number, the number of break points, and the ordinate, lb or in-lb, over abscissa, inches or rad, at each break point.

Note - extension is assumed to be positive for both ordinate and abscissa and 0.0 for the first break point indicates symmetry about the origin.

```
 PWL IBP Ordinates over Abscissae
------------------------------------------------------------------------
\PWL DATA
! ************************ Couplers **********************************
! Coupler to Ground Lead and Trail Ends
 1 2 0.0000E+00 1.0000E+01
   0.000000 1.000000
! Tow Rope to Ground Through C.G.
! 1500 LB/IN
 2 2 0.0000E+00 1.5000E+03
   0.000000 1.000000
 3 2 0.0000E+00 1.5000E+02
```

```
   0.000000 1.000000
! ********************* Center plate Connections ************************
! Longitudinal and lateral rim normal stiffness
! Steel on steel, with 80 lb/in +/-0.125 inch gap
 4 4 -1.1010E+03 -1.0000E+01 0.0000E+00 0.0000E+00
   -0.126000 -0.125000 0.000000 1.000000
! Vertical lift off spring for center plate
! The center plate stiffness has been increased from 1xE6 to 1xE7 to
! improve the roll calculation.
! with initial offsets
!Empty
! 5 3 -9.8000E+02 0.0000E+00 0.0000E+00
!   0.000000 0.000098 1.000000
! Loaded
 5 3 -3.0730E+04 0.0000E+00 0.0000E+00
   0.000000 0.0030730 1.000000
! Damping of center plate
 6 2 0.0000E+00 1.0000E+03
   0.000000 1.000000
! ********************* Roller Side Bearings *****************************
! Lift off spring for side bearings
! 7 3 -1.0000E+06 0.0000E+00 0.0000E+00
!   -1.000000 0.000000 1.000000
! Damping of side bearings
! 8 2 0.0000E+00 0.0000E+00
!   0.000000 1.000000
! ********************* Constant Contact Side Bearings *********************
! TCC-III-45 Long Travels
 9 7 -8.8000E+03 -7.8000E+03 -5.8000E+03 -4.3000E+03 -1.8000E+03 0.0000E+00
0.0000E+00
   -0.626000 -0.625000 -0.312500 0.000000 0.500000 1.000000 2.000000
! CCSB Damping
 10 3 0.0000E+00 1.0000E+03 1.0000E+03
```

```
   0.000000 0.050000 1.000000
! ********************* Bolster to Side Frame Connections ******************
! Longitudinal
 11 2 0.0000E+00 1.0000E+06
   0.000000 1.000000
 12 2 0.0000E+00 1.0000E+03
   0.000000 1.000000
! Pitch Stiffness and Stops Mid Tolerance is Approx +/- 2.4 Degrees=0.042mRad
 13 3 0.0000E+00 0.0000E+00 6.4000E+07
   0.000000 0.042000 1.042000
! ****************** Warp resistance ***********************************
! worn truck
! Warp resistance for bolster to side frame
! 14  3  0.0  5.25E04 6.924E05
!     0.0  0.030  0.040
! New truck
! Warp resistance for bolster to side frame
 14 3 0.0000E+00 2.5500E+05 8.9500E+05
   0.000000 0.030000 0.040000
! Stiff H-frame truck
! Warp resistance for bolster to side frame
! 14  3  0.0  1.275E06 1.915E06
!     0.0  0.030  0.040
! ************************* Empty Secondary******************************
! LATERAL STIFFNESS OF BOLSTER TO SIDE FRAME CONNECTION FOR ONE OF 4
EFFECTIVE SPRINGS in pounds and inches
! 6-D5 OUTER 7-D6 INNER 4-D6A INNER/INNER SPRINGS
! 15 3 0.000E+0 1.369E+3 1.014E+5
!   0.0000 0.5000 0.6000
! VERTICAL SUSPENSION WITH STATIC DEFLECTIONS FOR 4 EQUIVALENT
SPRINGS
! 6-D5 OUTER 7-D6 INNER 4-D6A INNER/INNER SPRINGS
!IN LBS AND INCHES
```

! 16 9 -4.717E+4 -2.217E+4 -1.413E+3 -1.051E+3 -6.781E+2 0.000E+0 0.000E+0 0.000E+0 0.000E+0

! -3.5858 -3.4858 -0.1733 -0.1108 0.0000 0.2017 1.1392 1.2642 2.2642

! FRICTION WEDGE CONTROL SPRING STIFFNESS FOR EQUIVALENT SPRINGS

! 2-B353 O OUTER CONTROL 2-B354 I INNER CONTROL COILS

! 17 9 -5.903E+4 -9.031E+3 -2.615E+3 -2.494E+3 -2.279E+3 -1.888E+3 -7.225E+1 0.000E+0 0.000E+0

! -3.5858 -3.4858 -0.1733 -0.1108 0.0000 0.2017 1.1392 1.2642 2.2642

! ****************** Loaded secondary*************************************

! LATERAL STIFFNESS OF BOLSTER TO SIDE FRAME CONNECTION FOR ONE OF 4 EFFECTIVE SPRINGS in pounds and inches

! 6-D5 OUTER 7-D6 INNER 4-D6A INNER/INNER SPRINGS LS

15 3 0.000E+0 1.981E+3 1.020E+5

0.0000 0.5000 0.6000

! VERTICAL SUSPENSION WITH STATIC DEFLECTIONS FOR 4 EQUIVALENT SPRINGS

! 6-D5 OUTER 7-D6 INNER 4-D6A INNER/INNER SPRINGS LS

!IN LBS AND INCHES

16 7 -4.717E+4 -2.217E+4 -1.351E+4 -1.413E+3 -1.051E+3 0.000E+0 0.000E+0

-1.4815 -1.3815 0.0000 1.9310 1.9935 2.3060 4.3685

! FRICTION WEDGE CONTROL SPRING STIFFNESS FOR EQUIVALENT SPRINGS

! 2-B353 O OUTER CONTROL 2-B354 I INNER CONTROL COILS

17 9 -5.903E+4 -9.031E+3 -6.355E+3 -2.615E+3 -2.494E+3 -1.888E+3 -7.225E+1 0.000E+0 0.000E+0

-1.4815 -1.3815 0.0000 1.9310 1.9935 2.3060 3.2435 3.3685 4.3685

!****************** Bearing Adapter Side Frame to Axle ********************

! Vertical Bearing adapter connection with offset for static load

!Empty

! 18 3 -2.1240E+03 0.0000E+00 0.0000E+00

! 0.000000 0.002124 1.000000

! Loaded

18 3 -1.6999E+04 0.0000E+00 0.0000E+00

0.000000 0.016999 1.000000

! Vertical Bearing adapter damping

```
 19 2 0.0000E+00 1.0000E+03
   0.000000 1.000000
! Bearing adapter stops
! Longitudinal Stiffness with Stops
 20 3 0.0000E+00 1.0000E+00 1.0000E+03
   0.000000 0.046800 0.047800
! Lateral Stiffness with Stops
 21 3 0.0000E+00 1.0000E+00 1.0000E+03
   0.000000 0.250000 0.251000
! Yaw Stiffness with Stops
 22 3 0.0000E+00 0.0000E+00 6.4000E+05
   0.000000 0.030000 0.040000
```

Appendix H.
Critical Speeds and Frequencies for Empty and Loaded Tank Cars

Critical Speeds and Frequencies for Models

Figure H 1 shows the typical modes of vibrations for the modeled vehicles.

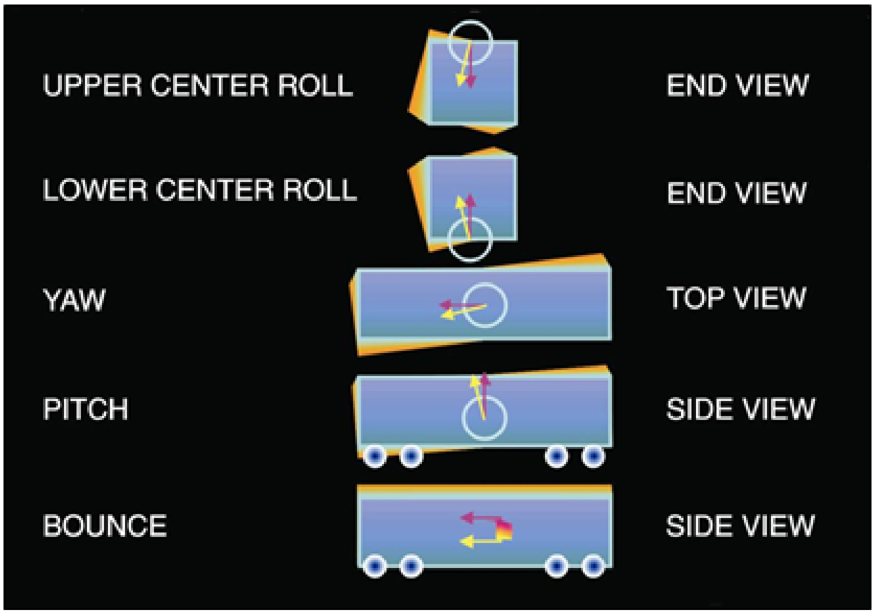

Figure H 1. Rigid Body Modes of Vibration

Figure H 1 shows the critical frequencies for each rigid body vibration. Table H 1 shows the key for tables and plots.

- Lower Center Roll (LCR): Roll about a point below the effective lateral suspension
- Bounce: End-to-end in phase vertical motion
- Yaw: End-to-end out of phase lateral motion
- Upper Center Roll (UCR): Roll about a point above the effective lateral suspension
- Pitch: End-to-end out of phase vertical motion

Table H 1. Critical Frequencies

Mode/Model	Loaded Hopper (hz)	Loaded Tank (hz)	Loaded Flat (hz)	Empty Hopper(hz)	Empty Tank (hz)	Empty Flat (hz)
LCR	0.776	0.789	0.806	1.830	1.574	2.655
Bounce	2.072	2.196	2.244	4.462	3.774	4.313
Yaw	2.289	2.320	2.563	4.856	4.311	4.588
UCR	2.846	3.119	3.190	5.767	5.772	5.153
Pitch	3.094	4.074	3.289	7.254	5.786	6.412

The results shown in Table H 1 were obtained from an EigenValue analysis of the NUCARS system files. These results are consistent with expected typical railroad vehicles. Figure H 2 though Figure H 7 are the resulting critical speed versus frequency analysis for all the vehicles used in these simulations, excluding the empty hopper car. The empty hopper car results were added for completeness. Each figure shows a line representing typical track wavelengths of input (19.5 to 124 feet) and the critical mode of vibration frequency for each vehicle simulated. Where each vertical line representing the mode of vibration crosses the wavelength line is the critical speed for that particular mode. For example, the critical LCR mode for the loaded hopper car is 0.776 from Table H 1 crosses the 39.0-foot wavelength line at 16.6 miles per hour (mph). This is an expected LCR critical speed for a loaded hopper or gondola car. These plots can also be used to extrapolate either between frequencies or wavelengths. For example, if a measured track wavelength was 100 feet, then the critical speed expected for LCR would be roughly 48 mph.

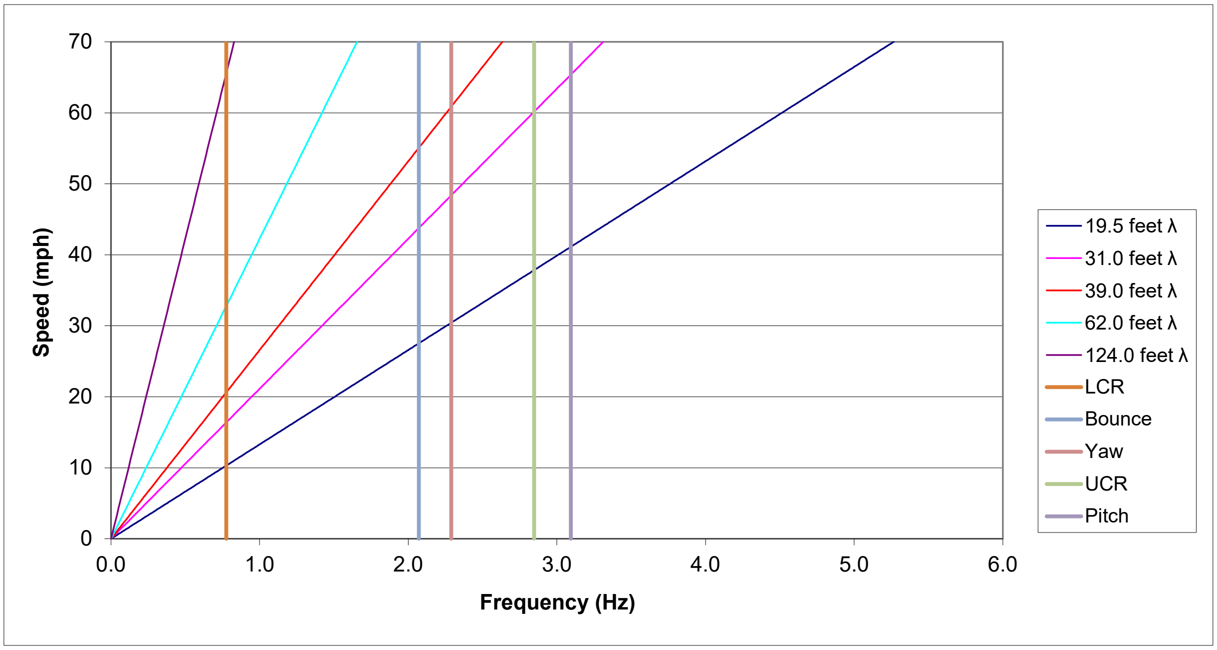

Figure H 2. Loaded Hopper Car Frequency Analysis

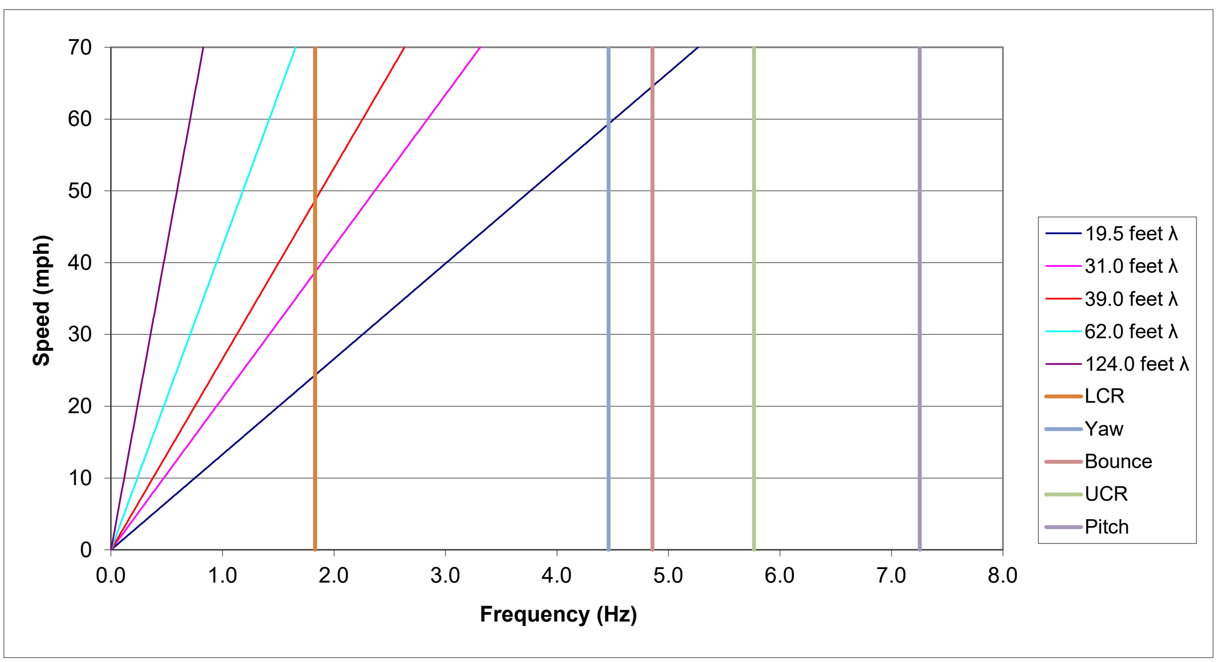

Figure H 3. Empty Hopper Car Frequency Analysis

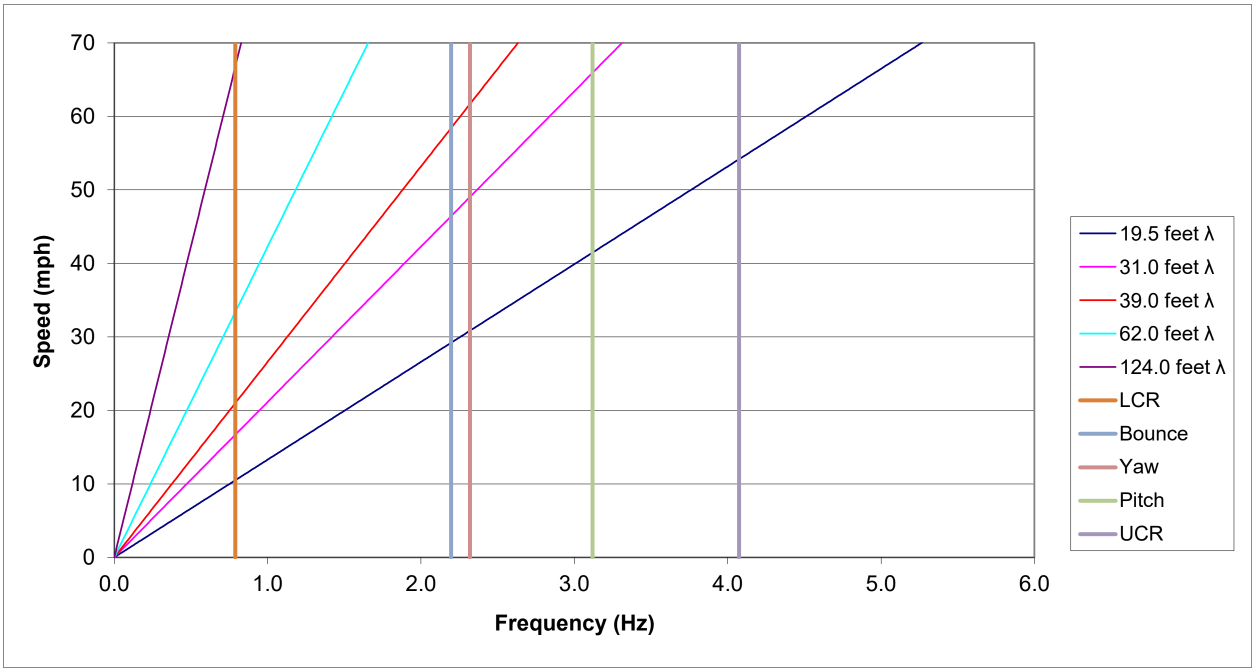

Figure H 4. Loaded Tank Car Frequency Analysis

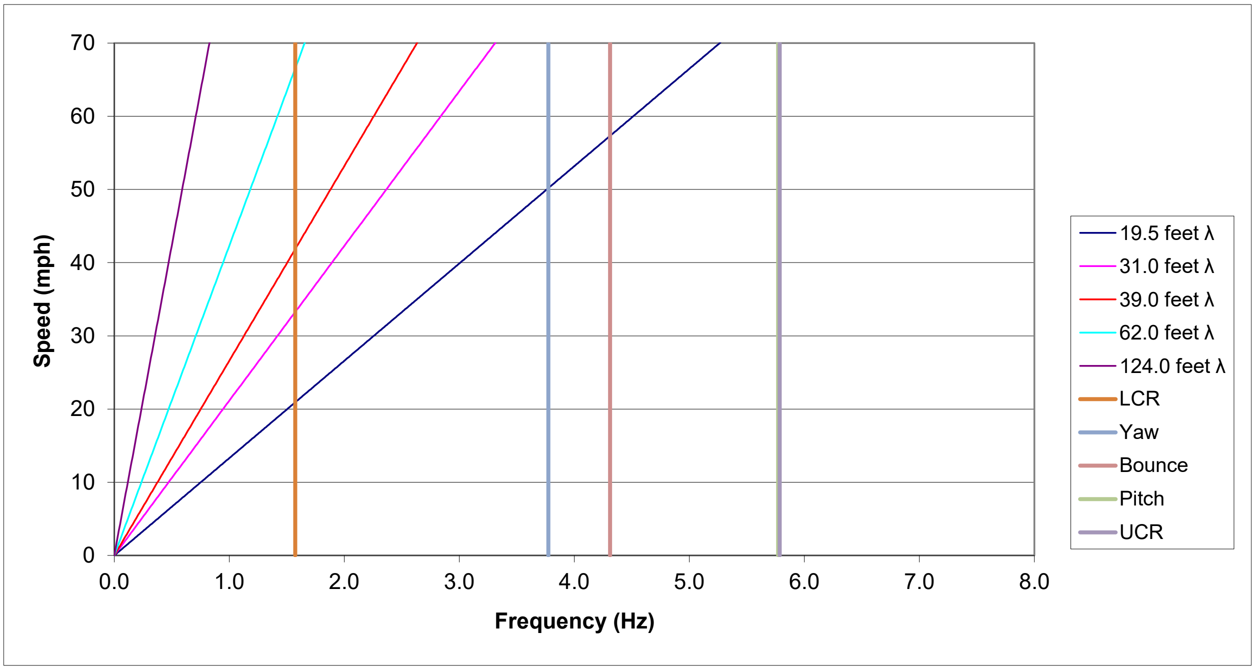

Figure H 5. Empty Tank Car Frequency Analysis

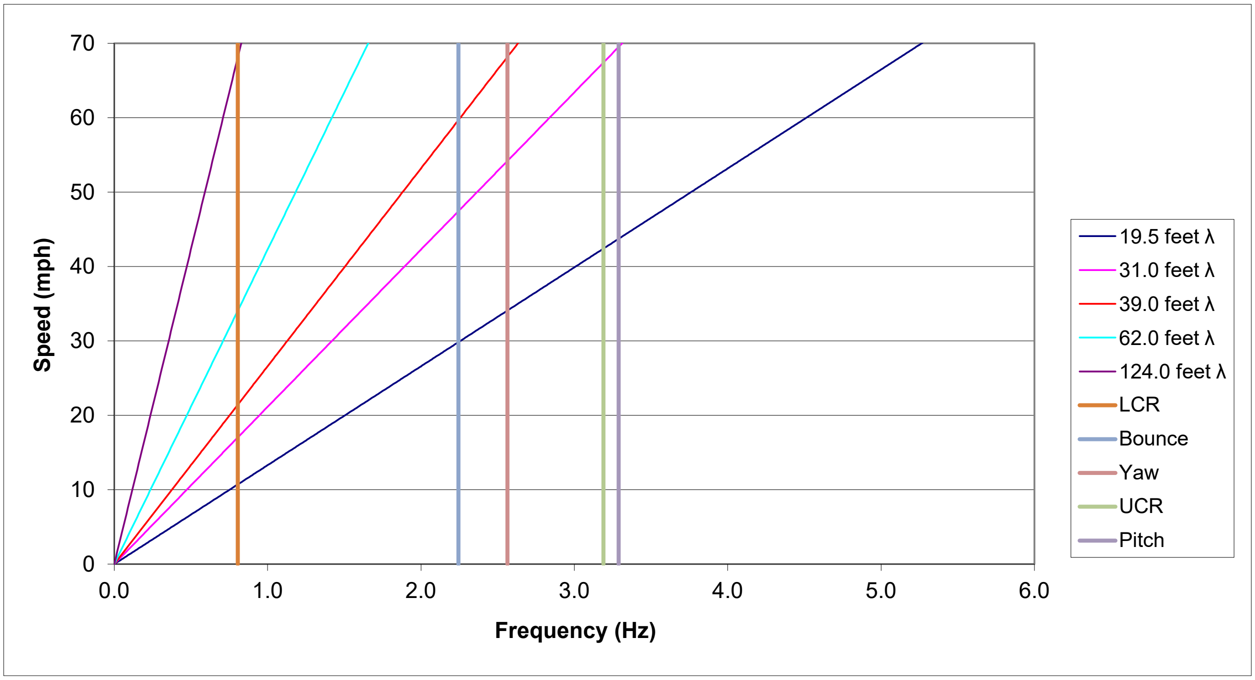

Figure H 6. Loaded Flat Car Frequency Analysis

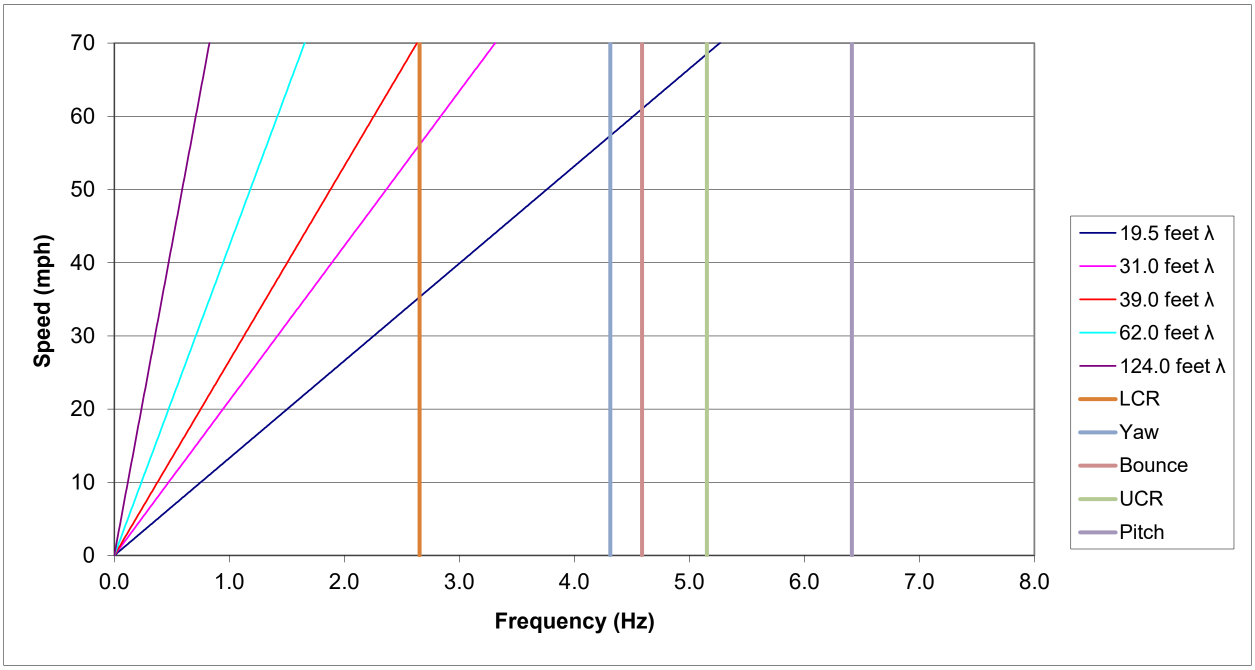

Figure H 7. Empty Flat Car Frequency Analysis

The EigenValue results presented in Figure H 2 through Figure H 7 are broken down into Table H 2 through Table H 6, showing the critical speeds for each mode of vibration and resulting speed.

Table H 2. Critical Speeds, 19.5-foot Wavelength

Mode/Model	Loaded Hopper(mph)	Loaded Tank(mph)	Loaded Flat(mph)	Empty Hoppe(mph)r	Empty Tank(mph)	Empty Flat(mph)
LCR	10.63	10.00	10.63	23.53	35.89	34.96
Bounce	27.38	28.98	29.51	58.76	57.17	56.9
Yaw	30.31	30.44	34.16	64.48	61.15	60.76
UCR	37.62	41.21	42.27	>70	67.8	67.93
Pitch	40.95	53.58	43.69	>70	>70	>70

Table H 3. Critical Speeds, 31.0-foot Wavelength

Mode/Model	Loaded Hopper(mph)	Loaded Tank(mph)	Loaded Flat(mph)	Empty Hopper(mph)	Empty Tank(mph)	Empty Flat(mph)
LCR	16.60	16.48	16.90	38.48	32.55	56.01
Bounce	43.75	46.07	47.34	>70	>70	>70
Yaw	48.61	49.82	54.32	>70	>70	>70
UCR	60.00	65.73	67.42	>70	>70	>70
Pitch	65.31	>70	70.00	>70	>70	>70

Table H 4. Critical Speeds, 39.0-foot Wavelength

Mode/Model	Loaded Hopper(mph)	Loaded Tank(mph)	Loaded Flat(mph)	Empty Hopper(mph)	Empty Tank(mph)	Empty Flat(mph)
LCR	21.00	21.00	21.53	48.12	41.48	>70
Bounce	54.77	57.70	59.56	>70	>70	>70
Yaw	60.62	61.69	67.80	>70	>70	>70
UCR	>70	>70	>70	>70	>70	>70
Pitch	>70	>70	>70	>70	>70	>70

Table H 5. Critical Speeds, 62-foot Wavelength

Mode/Model	Loaded Hopper(mph)	Loaded Tank(mph)	Loaded Flat(mph)	Empty Hopper(mph)	Empty Tank(mph)	Empty Flat(mph)
LCR	32.55	32.97	33.39	>70	66.38	>70
Bounce	>70	>70	>70	>70	>70	>70
Yaw	>70	>70	>70	>70	>70	>70
UCR	>70	>70	>70	>70	>70	>70
Pitch	>70	>70	>70	>70	>70	>70

Table H 6. Critical Speeds, 124.0-foot Wavelength

Mode/Model	Loaded Hopper(mph)	Loaded Tank(mph)	Loaded Flat(mph)	Empty Hopper(mph)	Empty Tank(mph)	Empty Flat(mph)
LCR	65.95	66.79	68.48	>70	>70	>70
Bounce	>70	>70	>70	>70	>70	>70
Yaw	>70	>70	>70	>70	>70	>70
UCR	>70	>70	>70	>70	>70	>70
Pitch	>70	>70	>70	>70	>70	>70

Abbreviations and Acronyms

ACRONYM	DEFINITION
AAR	Association of American Railroads
CCSB	Constant Contact Side Bearings
CG	Center-of-Gravity
CFR	Code of Federal Regulations
FRA	Federal Railroad Administration
Hz	Hertz
LCR	Lower Center Roll
L/V	Lateral to Vertical
MCO	Mid-Chord Offsets
TTCI	Transportation Technology Center, Inc. (the company)
UCR	Upper Center Roll