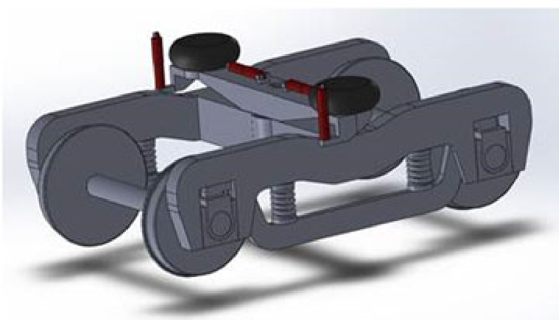
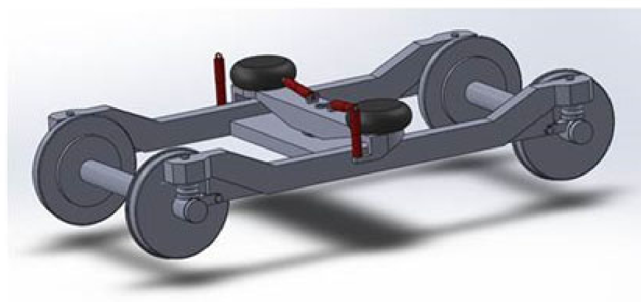
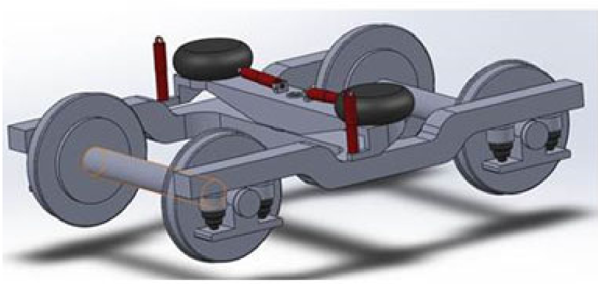
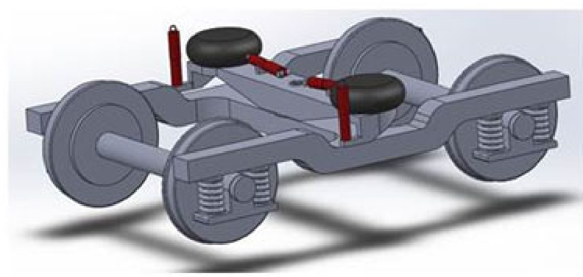
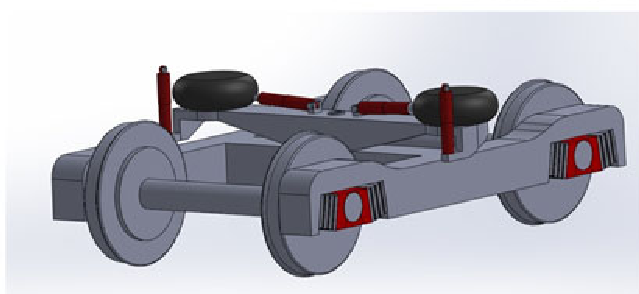
U.S. Department
of Transportation

Federal Railroad
Administration

Office of Research,
Development and Technology
Washington, DC 20590

Design Considerations for High-Speed Trucks on Passenger Vehicles

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14. ABSTRACT
This report presents an evaluation of high-speed passenger trucks for use in shared freight and passenger corridors. The primary focus of the report is on vehicle dynamic response for a range of low and high speed performance regimes adapted from the Federal Railroad Administration (FRA), Association of American Railroads (AAR), and American Public Transportation Association (APTA) standards. A matrix of existing truck designs was developed, and NUCARS® simulations were performed for five "generic" truck types to assess and compare their dynamic performance capabilities. Evaluations included quantifying the effects on the load environment including wheel-rail wear, vertical and lateral dynamic wheel load and ride quality. Example simulation matrices and test matrices for vehicle qualification and model validation were developed. Conclusions included recommendations for changes to the lateral/vertical (L/V) distance to climb and minimum percent wheel load performance criteria. No single truck design was identified as having the best performance in all performance regimes. Results demonstrate the design trade-offs that must be evaluated by truck designers to optimize performance.

15. SUBJECT TERMS
Shared corridor, high-speed passenger trucks, truck design, vehicle-track interaction, vehicle dynamic performance criteria, lateral/vertical, L/V, wheel unloading, low speed derailment, Minimally Compliant Analytic Track, MCAT, AAR Chapter 11, American Public Transportation Association, APTA, NUCARS®, rolling stock, passenger service

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METRIC/ENGLISH CONVERSION FACTORS

ENGLISH TO METRIC

LENGTH (APPROXIMATE)

1 inch (in)	=	2.5 centimeters (cm)
1 foot (ft)	=	30 centimeters (cm)
1 yard (yd)	=	0.9 meter (m)
1 mile (mi)	=	1.6 kilometers (km)

AREA (APPROXIMATE)

1 square inch (sq in, in^2)	=	6.5 square centimeters (cm^2)
1 square foot (sq ft, ft^2)	=	0.09 square meter (m^2)
1 square yard (sq yd, yd^2)	=	0.8 square meter (m^2)
1 square mile (sq mi, mi^2)	=	2.6 square kilometers (km^2)
1 acre = 0.4 hectare (he)	=	4,000 square meters (m^2)

MASS - WEIGHT (APPROXIMATE)

1 ounce (oz)	=	28 grams (gm)
1 pound (lb)	=	0.45 kilogram (kg)
1 short ton = 2,000 pounds (lb)	=	0.9 tonne (t)

VOLUME (APPROXIMATE)

1 teaspoon (tsp)	=	5 milliliters (ml)
1 tablespoon (tbsp)	=	15 milliliters (ml)
1 fluid ounce (fl oz)	=	30 milliliters (ml)
1 cup (c)	=	0.24 liter (l)
1 pint (pt)	=	0.47 liter (l)
1 quart (qt)	=	0.96 liter (l)
1 gallon (gal)	=	3.8 liters (l)
1 cubic foot (cu ft, ft^3)	=	0.03 cubic meter (m^3)
1 cubic yard (cu yd, yd^3)	=	0.76 cubic meter (m^3)

TEMPERATURE (EXACT)

[(x-32)(5/9)] °F = y °C

METRIC TO ENGLISH

LENGTH (APPROXIMATE)

1 millimeter (mm)	=	0.04 inch (in)
1 centimeter (cm)	=	0.4 inch (in)
1 meter (m)	=	3.3 feet (ft)
1 meter (m)	=	1.1 yards (yd)
1 kilometer (km)	=	0.6 mile (mi)

AREA (APPROXIMATE)

1 square centimeter (cm^2)	=	0.16 square inch (sq in, in^2)
1 square meter (m^2)	=	1.2 square yards (sq yd, yd^2)
1 square kilometer (km^2)	=	0.4 square mile (sq mi, mi^2)
10,000 square meters (m^2)	=	1 hectare (ha) = 2.5 acres

MASS - WEIGHT (APPROXIMATE)

1 gram (gm)	=	0.036 ounce (oz)
1 kilogram (kg)	=	2.2 pounds (lb)
1 tonne (t)	=	1,000 kilograms (kg)
	=	1.1 short tons

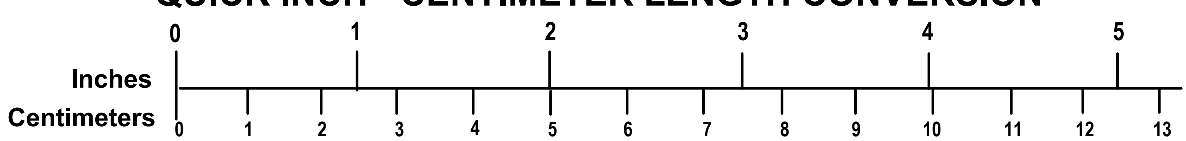
VOLUME (APPROXIMATE)

1 milliliter (ml)	=	0.03 fluid ounce (fl oz)
1 liter (l)	=	2.1 pints (pt)
1 liter (l)	=	1.06 quarts (qt)
1 liter (l)	=	0.26 gallon (gal)
1 cubic meter (m^3)	=	36 cubic feet (cu ft, ft^3)
1 cubic meter (m^3)	=	1.3 cubic yards (cu yd, yd^3)

TEMPERATURE (EXACT)

[(9/5) y + 32] °C = x °F

QUICK INCH - CENTIMETER LENGTH CONVERSION



QUICK FAHRENHEIT - CELSIUS TEMPERATURE CONVERSION

°F	-40°	-22°	-4°	14°	32°	50°	68°	86°	104°	122°	140°	158°	176°	194°	212°
°C	-40°	-30°	-20°	-10°	0°	10°	20°	30°	40°	50°	60°	70°	80°	90°	100°

For more exact and or other conversion factors, see NIST Miscellaneous Publication 286, Units of Weights and Measures. Price $2.50 SD Catalog No. C13 10286

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Contents

Illustrations

Tables

Executive Summary

Transportation Technology Center, Inc. (TTCI) conducted an evaluation of existing high-speed passenger truck designs for use in shared freight and passenger operations in North America up to 125 mph (201 km/h) for the Federal Railroad Administration (FRA). High-speed, intercity, and commuter types of passenger equipment were considered. However, researchers used existing designs and design guidelines for high-speed passenger trucks.

The project focused primarily on high-speed rail vehicle-track interaction encompassing dynamic performance and operating environment, which included information on braking systems and bearing monitoring systems. Because design data for specific truck types was not available from manufacturers, the analysis was performed for five generic truck primary suspension types: radial arm, equalizer beam, rubber chevron, conical spring, and journal spring. The work included:

- Development of a matrix of existing high-speed truck designs
- Generic model development for five suspension types
- Simulations of dynamic response for high- and low-speed conditions adapted from existing FRA, Association of American Railroads (AAR), and American Public Transit Association (APTA) performance standards
- Quantifying the load environment, including wheel-rail wear, vertical and lateral dynamic loading on the track and ride quality
- Recommendations for simulation validation and test matrices

No single truck design evaluated stood out as having better overall performance than another. A truck design that performs better than other designs in one regime often performs worse than other designs in another regime. For example, the equalizer beam truck performed well in the wheel load equalization and low-speed derailment analyses, but also produced the highest wheel-rail wear results.

Because all the simulation and analyses were performed for hypothetical "generic" representative truck designs, none of the results and conclusions presented should be used to identify an individual truck design as being the "best" or "worst" for a particular performance regime or service application. Instead, the results should be used to understand the challenges and design trade-offs that must be met to develop a vehicle and suspension for operation on shared freight and passenger corridors with a wide range of track classes.

A significant conclusion of the results is that the 5-foot distance to climb lateral-to-vertical (L/V) criterion specified in FRA's Title 49 Code of Federal Regulations § 213.345 is too long, and a shorter criterion such as the 50 milliseconds (msec) criterion specified in the AAR Manual of Standards and Recommended Practices (MSRP) Standard M-1001, Chapter 11 is more appropriate for the evaluation of low-speed flange climb performance [1] [2].

In addition, simulation results showed that the 10 percent of static wheel load vertical wheel load criterion was not a good predictor of low speed derailment performance and wheel load equalization. A criterion of 30 percent may be more appropriate.

A limited set of parametric variations were performed to demonstrate how tuning of the suspension could improve performance in specific regimes. To completely optimize a particular truck design, the revised suspension design would need to be reevaluated against all the different performance regimes to verify that the change did not adversely affect performance in any other regime.

1. Introduction

In response to the expansion of high-speed intercity passenger rail service in the United States, the Federal Railroad Administration (FRA) has identified a need to research high-speed truck performance in mixed operations. Shared right-of-way operation is a different and demanding service environment for both vehicles and track. With mixed operations, track is subjected to a wider range of operating conditions (e.g., speed, wheel load, wheel profile, and truck suspension characteristics). Additionally, rolling stock of all types must perform well within the "best compromise" track design and maintenance requirements. This represents a systems optimization challenge. Design and maintenance of track need to address passenger and freight operations while ensuring safety and ride quality. Designs of rolling stock need to consider the track geometry optimized for shared operations and the load environment. Transportation Technology Center, Inc. (TTCI) conducted this research for FRA to address the steps in refining the passenger truck design parameters to assure optimized operation in a mixed traffic environment.

1.1 Objectives and Scope

This study evaluated existing designs, developed general design guidelines for high-speed passenger trucks for use in shared operations, and identified one or more potentially usable trucks for use in the North American context. The passenger equipment considered was of the high-speed, intercity, and commuter types, but did not include heavy or light rail mass transit systems. The study includes an evaluation of truck retrofit or improvement strategies to address shared passenger and freight operation issues and updates to FRA's 1996 suspension data report with modeling parameters of trucks presently in use [3]. Information on braking systems and bearing monitoring systems currently used on high-speed railroad trucks is included as well to bring awareness to these factors as they influence truck design. A study of high-speed rail vehicle-track interaction encompassing dynamic performance and the operating environment was the primary focus of this project.

1.2 Overall Approach

The project was organized by the following tasks:

- **Review of existing truck designs**: TTCI consulted with industry stakeholders to identify the state-of-the-art high-speed truck technologies around the world. Truck technologies have been grouped and analyzed according to truck type. The relevant specifications/data to facilitate vehicle dynamics modeling have been listed.
- **Identify truck technologies for upgrades**: TTCI has identified representative truck design features to determine which truck types are the most suitable for further analysis.
- **Develop vehicle/truck numerical models**: TTCI created vehicle dynamics models for high-speed passenger trucks as identified above. These included conceptual design studies for emerging technologies such as active dampers for active suspensions and composite materials for springs and truck frames, where truck frame flex is part of the

suspension. All modeling was performed using TTCI's NUCARS®[1] vehicle-track interaction simulation software.

- **Model validation test matrix**: TTCI produced a test matrix describing the tests and measurements required for validating the numerical models. This matrix can be used for future on-track testing.
- **Analyze alternatives and improvements**: At the onset of the project TTCI intended to use the numerical models developed in the previous tasks to investigate issues such as how the different designs perform with U.S. wheel profiles, wheel-rail wear studies, truck component fatigue analysis, and track maintenance requirements to preserve acceptable dynamic performance. However, due to the lack of available design data for actual truck designs it was not possible to perform a realistic assessment of the different trucks. Braking system technologies and options within the context of truck design was evaluated but due to the lack of available design data it was not possible to realistically identify potential options and improvements. Onboard and wayside monitoring technologies for brakes and bearings have been listed. Brakes and monitoring technologies are an essential part of the overall system and are often incorporated into the truck design. Analysis was limited to a qualitative description of how these designs may affect dynamic performance.
- **Recommend design considerations for improvement**: At the onset of the project TTCI intended to provide descriptions of methods for evolving existing technologies into the U.S. operating environment. This was intended to include suggesting retrofit strategies for upgrading existing trucks. However, due to the lack of available data for actual truck designs it was not possible to evaluate the technologies and develop specific recommendations. Therefore, a few example parametric evaluations were conducted to demonstrate the types of evaluations a truck designer would need to conduct to optimize their designs.
- **Quantifying the loading environment**: The operating environment directly affects the performance of railroad vehicles and accurate knowledge of the load environment is necessary for estimating truck component life expectancy. TTCI has performed simulations of the different truck designs operating over three representative shared freight and passenger corridors and compared the results to typical freight vehicle performance. Evaluations included an analysis of wheel-rail wear indices, vertical and lateral wheel loads and passenger ride quality.

1.3 Organization of the Report

This report provides information about the truck designs of the high-speed passenger car in Section 2; details of the development of the NUCARS® truck model and its criteria in Section 3; Section 4 presents the quantification of the wear index; Section 5 provides information on validation of the test matrix; and Section 6 summarizes the research and its findings, as well as provides recommendations. Appendices A through H offer additional information.

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

2. High-Speed Passenger Car Truck Designs

The benchmark study reveals the current state-of-the-art designs for existing passenger trucks worldwide. TTCI, in conjunction with Parsons Brinckerhoff, conducted internet research and consulted with industry stakeholders with an emphasis on European and Asian high-speed passenger equipment. Although the assignment was initially limited to unpowered trucks, the current trend in high-speed rail rolling stock has included distributed power through the train. This section includes information about powered rolling stock, but it is not considered in further sections.

2.1 Background

This section provides a discussion of the approach taken in developing the improvement considerations of existing, state-of-the-art truck technologies for adaptation to U.S. operating environments. This benchmark study primarily involves the research of powered and unpowered high-speed passenger car truck designs used in Europe and Asia. The results of this research, obtained via the internet and from consultation with industry stakeholders, contributed to the next steps necessary in refining the passenger truck design parameters and in developing vehicle-track numerical models.

2.1.1 Definitions

The following definitions are helpful in describing the terminology used in high-speed passenger car designs/operations and referenced in this report:

Above top of rail – ATOR

Articulations – A trainset design whereby two adjacent cars share a common truck.

Axle – A solid or hollow circular shaft that connects two wheels to form a wheelset.

Inboard – Bearings located in the interior to the truck frame.

Outboard – Bearings located in the exterior to the truck frame.

Car – A single vehicle unit that, when coupled with other cars, form a trainset or consist.

Diesel multiple unit (DMU) – A diesel-powered multiple unit with one or more propelling motors designed to carry passenger traffic [3].

Dual-mode – The capability of running on diesel or electrified territories.

Eddy current brake – A rail brake or a disc brake system used to reduce the speed of the equipment via electromagnetic induction. Eddy current brakes are contactless.

Electric multiple unit (EMU) – An electric-powered multiple unit with one or more propelling motors designed to carry passenger traffic.

Equalizer spring – Springs that form part of the primary suspension system that connects the equalizer beam to the truck frame.

Forced steering – The use of linkages between the carbody, truck frame, and axles to force the axles into a radial position [3].

Friction braking – A contact-based brake system used to retard the speed of the train.

Disk brake – A friction brake that includes a caliper/disc assembly to decelerate the train. The discs may either be flat metal components installed on the axles or the wheel itself (i.e., cheek brakes).

Tread brake – Also known as on-tread friction brake, a friction brake whereby a brake shoe engages/interfaces with the wheel tread to decelerate the train. In instances where tread brakes are not provided, tread cleaners may be installed.

Track brake – A friction brake that engages/interfaces with the rail head to decelerate the train.

High-speed rail – A rail service having the characteristics of intercity rail service which operates primarily on a dedicated guideway or unused track, for the most part, by freight, including, but not limited to, trains on welded rail, magnetically levitated (maglev) vehicles on a special guideway, or other advanced technology vehicles, designed to travel at speeds in excess of those possible on other types of railroads [42].

High-speed train – Rail equipment used for high-speed rail service. This report focuses only on steel-wheel-on-steel-rail technologies.

Independent wheels –Each wheel of the same wheelset rotates independently. Independent wheels are used mainly when a solid axle conflicts with a desired vehicle feature (e.g., low floor), but also may produce beneficial changes in how the vehicle negotiates curves and achieves dynamic stability [3].

Intercity train – A passenger train that provides service between large cities [42].

Journal spring – Springs for the primary suspension system located above or alongside the axle box. Journal springs truck variants include the use of coil springs, rubber chevron springs, radial arms, leaf springs, etc.

Multi-level – Equipment with more than one level of space used for passenger accommodations.

Passenger train – A train that transports or is available to transport members of the general public.

Passive steering – The use of interconnecting axles of a truck to allow relative yaw movements at the same time as providing a high stiffness against relative shear of the axles [3].

Power car – A rail vehicle that propels a passenger train or is the lead vehicle in a passenger train, or both.

Powered truck – A truck equipped with traction equipment.

Primary suspension – The suspension system connecting the wheelset to the truck frame, and providing the required stiffness and freedom of movement in all coordinates [3].

Radial steering – A system consisting of linkages/mechanical elements that permits radial movement of wheelsets in curves.

Regenerative braking – The return of energy generated by the equipment into the electrification system or as addressed by an onboard power management system.

Regional train – A passenger train, also known as a commuter train, providing commuter service within an urban, suburban, or metropolitan area.

Rheostatic braking – The dissipation of energy generated by the equipment via onboard resistor grids.

Secondary suspension – The suspension system connecting the truck frame to the carbody, and providing the required stiffness and freedom of movement in all coordinates [3].

Single Axles – The suspension system is placed directly between a single wheelset and the carbody [3].

Single-level – Equipment with one level of space used for passenger accommodations.

Suspension system – The entire assembly of wheels, springs, dampers, load-bearing structure, and other components which support the vehicle carbody [3].

Tier I – Operating at speeds not exceeding 125 mph (201 km/h) [42].

Tier III – Operating at speeds greater than 125 mph (201 km/h) and as further defined by FRA.

Tilt – A mechanism installed onboard that permits the equipment to tackle curves at a higher velocity while reducing the centrifugal force effects on passengers and crew.

Active tilt – Tilting caused via computer control.

Passive tilt – Tilting caused by inertial forces.

Trailer car – Rail rolling equipment intended to provide transportation for members of the general public that is without propelling motors and without a control stand [42]. Also known as a passenger coach.

Trainset – A train consisting of semi-permanently attached cars.

Truck frame – This provides a structural connection between the primary and secondary suspension. The truck frame may be a one-piece rigid structure, or may incorporate articulation joints or flexible structures [3].

Unpowered truck – A truck not equipped with traction equipment.

Wheelset – Consists of two wheels connected by an axle supported on journal bearings. Usually, the wheels are rigidly fixed to the axle, but a few designs allow the wheels to rate independently on the axle instead of using journal bearings.

2.2 Development of the Candidate Truck Matrix

Table 1 shows a candidate truck matrix created with criteria using Table 2 as a guideline. Table 2 was developed as part of the Bing (1996) study that captured, grouped, and classified truck models used in U.S. service at that time [3]. The completed candidate truck matrix including 33 truck/vehicle types is presented in Appendix A [4–62]. Matrices for individual categories of trucks are presented in Appendix B [4–62].

Table 1. High-Speed Candidate Truck Matrix

Car/Trainset	Primary Car/Trainset Manufacturer	Owner/Operator	Series Name	Operation	Body Type	Body Width	Car/Trainset Maximum Operating Speed	Truck Maximum Speed	Car/Trainset Weight (Tare)	Truck	Truck Manufacturer	Powered or Unpowered	Gage
…	…	…	…	…	…	…	…	…	…	…	…	…	…

Primary Suspension	Secondary Suspension	Bearing Location	Specialized Feature 1	Specialized Feature 2	Specialized Feature 3	Type of Braking System	Additional Comments
…	…	…	…	…	…	…	…

Table 2. Passenger Car Population Data by Truck Classification [3]

Car Series Designation	Owner	Contract Operator (if different)	Type of Operation	Series Name (where used)	Manufacturer	Number in Service	Dates Put into Service	Powered or Unpowered	Body Type	Car Description			Truck Description			
										Typical Maximum Speed	Approximate Total Weight	Comments	Manufacturer	Model	Classification	Comments

The truck matrix developed for this study includes new high-speed, intercity, and regional equipment currently in operation, or are planned to be in operation overseas. It also lists several rolling stock that are currently in service in the United States and may take value from the results of this project. The focus of this study is limited to technologies that fall within U.S. Tier I operations; as such, the equipment listed have maximum operating speeds not exceeding 125 mph (201 km/h).

2.2.1 Matrix — Equipment Information

The following provides a summary of each heading presented in appendices A and C.

Car/Trainset

The name of the rolling stock, as identified by the equipment manufacturer, is presented in this column. In several cases, where no name is identified, the body type (e.g., single-level coaches, bi-level coaches, etc.) is used.

Primary Car/Trainset Manufacturer

The name of the primary vehicle manufacturer is presented in this column. The research conducted to-date targeted key carbuilders who have had decades of experience with high-speed truck technologies and with international and/or U.S. operations. These entities included:

- Alstom
- Bombardier
- Construcciones y Auxiliar de Ferrocarriles (CAF)
- CRRC Qingdao Sifang (formerly CSR Qingdao Sifang)Hitachi (formerly Ansaldo Breda)
- Hyundai Rotem
- Kawasaki
- Nippon Sharyo
- Siemens
- Stadler
- Talgo

Owner/Operator

The name of the representative owner and/or operator of the equipment, as well as the country of operation, is presented in this column. In areas where the equipment is still in the conceptual/design stage, an owner/operator was not identified and the term “concept” was used.

Series Name

The name of the equipment, as set by the respective operator, is presented in this column. Where no operator was present, the term “N/A” was used.

Operation

The type of operation the equipment is used in is identified in this column and may fall under one of the following categories:

- Regional
- Intercity
- High-speed

Body Type

The equipment's carbody type is identified in this column and may fall under one of the following categories:

- Single-level EMU
- Single-level DMU
- Single-level trailer
- Single-level power
- Single-level dual
- Multi-level EMU
- Multi-level trailer
- Multi-level power

Body Width

The equipment's exterior carbody width is identified in this column and may fall under one of the following categories:

- Standard body: maximum width up to 10.5 feet (3.2 meters)
- Wide body: widths 10.5 feet (3.2 meters) and higher
- Standard/wide body: same equipment can be delivered in either width

Car/Trainset Maximum Operating Speed

The vehicle's maximum operating speed is identified in this column.

Truck Maximum Speed

The truck's maximum operating speed is identified in this column. In some instances, per the design of the truck, this speed may exceed that of the vehicle's maximum operating speed.

Car/Trainset Weight (Tare)

The tare weight of the vehicle is identified in this column. The value in brackets preceding the weight represents the number of cars associated with that weight.

Truck

The name of the truck is identified in this column and generated based on the name of the equipment in instances where the manufacturer did not offer one.

Truck Manufacturer

The name of the truck manufacturer is identified in this column. On several occasions, the truck manufacturer is different from the primary car/trainset manufacturer.

Powered or Unpowered

The motive capability of the truck is identified in this column and may fall under one of the following categories:

- Powered (as found in EMUs, DMUs, and/or locomotives)
- Unpowered (as found in EMUs, DMUs, and/or passenger coaches)
- Both (as found in EMUs and DMUs)

Gage

The distance between the inside faces of the rails. All equipment considered for this study accommodates a track gage of 56.5 inches (1,435 millimeters).

Primary Suspension

The primary suspension setup/features for the vehicle are identified in this column. For several types of equipment when the type of primary suspension could not be readily identified or no further information was found, the terms "N/A" or "journal spring" were used, as applicable.

Secondary Suspension

The secondary suspension setup/features for the vehicle is identified in this column. When the type of secondary suspension could not be readily identified or no further information was found, the term "N/A" was used.

Bearing Location

The location of the journal bearing is identified in this column and may fall under one of the following categories:

- Inboard
- Outboard

A discussion on current bearing health monitoring technologies is included in Section 2.3.

Specialized Feature 1

Any known specialized feature of the equipment/truck is identified in this column. Examples include:

- Articulated cars
- Single axles
- Independent wheels
- Passive steering
- Forced steering
- Active radial steering
- Passive tilt
- Active tilt

Specialized Feature 2

Refer to Specialized Feature 1.

Specialized Feature 3

Refer to Specialized Feature 1.

Type of Braking System

The type of braking system (e.g., friction, electric) and its respective elements (e.g., track brakes, regenerative, rheostatic, etc.) are identified in this column. Braking types are further described in Section 2.4.

Additional Comments

Any additional comments pertaining to the specific equipment/truck are identified in this column.

2.2.2 Matrix — Truck Information

Truck information for each vehicle identified in the candidate truck matrices are individually tabulated in Appendix D [8–62]. The parameters shown are critical to facilitate the modeling of vehicle dynamic performance in known operating environments to better understand high-speed rail vehicle-track interaction in mixed traffic conditions. In addition to the names of the truck manufacturer and its respective truck, the following information was included, where available:

- Running speed: the maximum speed that the truck is capable of operating
- Axle load: the maximum weight permitted to be imparted on a single axle
- Wheelbase: the center-to-center distance from one wheelset to another wheelset on the same truck. For equipment with single axles or independently rotating wheels, the center-to-center distance runs the length of the car.
- Wheel diameter new/worn: the respective maximum/minimum wheel diameters permitted to safely operate the vehicle
- Minimum curve radius: service/shop: the smallest curve radii that the truck may navigate on the mainline or in yards
- Truck height: the maximum height of the truck above top of rail
- Weight-powered: the weight of a powered truck (i.e., inclusive of traction equipment)
- Weight-unpowered: the weight of an unpowered truck (i.e., no traction equipment installed)

2.2.3 Types/Classification of Trucks

The first step of paring down the master candidate list in Appendix C [8–62] involved the removal of Tier III-capable equipment (e.g., AGV, Zefiro, Shinkansen, Velaro, etc.) as they were considered out-of-scope to this project. Intercity equipment that had maximum speeds greater than 125 mph (201 km/h) were also removed. Lastly, those vehicles that did not have primary/secondary suspensions and bearing information available were filtered out. The candidate matrix list, as shown in Appendix A, was then generated, which contained 33 out of the original 52 trucks. These 33 items were further broken down into the following individual categories, as listed in Appendix B, based on primary/secondary suspension and bearing characteristics:

- (9) Journal Spring – Air Spring – Outboard Bearings
- (2) Journal Spring – Air Spring/Center Pivot – Outboard Bearings
- (5) Journal Spring – Air Spring/Bolster – Outboard Bearings
- Journal Spring – Air Spring/Bolsterless – Outboard Bearings
- Journal Spring/Flexible Frame – Air Spring/Center Pivot – Outboard Bearings
- Journal Spring/Flexible Frame – Coil Spring/Bolster/Center Pivot – Outboard Bearings
- Sleeve Spring – Air Spring/Bolster/Center Pivot – Outboard Bearings
- Radial Arm – Air Spring/Bolster/Center Pivot – Outboard Bearings
- Radial Arm – Air Spring/Bolsterless – Outboard Bearings
- Radial Arm – Air Spring – Outboard Bearings
- Radial Arm/Coil Spring/Rubber – Air Spring – Outboard Bearings
- Rubber Chevron – Air Spring/Bolster – Inboard Bearings
- Rubber Metacone/Flexible Frame – Air Spring/Bolster/Center Pivot –Inboard Bearings
- Equalizer – Swing Hanger – Outboard Bearings
- Equalizer – Air Spring/Bolster/Center Pivot – Inboard Bearings
- Equalizer – Coil Spring/Bolster/Center Pivot – Outboard Bearings

TTCI used these categories to perform NUCARS® modeling as discussed in Section 3. In addition to the information provided in appendices A, B, and D, TTCI gathered modeling parameters from previous testing and modeling experience [8–62].

2.3 Bearing Monitoring Technologies

One of the aspects critical to vehicle operational safety is the health of the axle bearing. In the United States, rail operators typically install wayside-based monitoring systems that assess the temperature of the bearing as it passes through a sensor. In Europe, wayside monitoring is used for equipment with a maximum operating speed less than 155 mph (250 km/h). As the design of rail vehicles advances or higher speed operations are introduced, onboard monitoring and diagnostics are used to provide real-time assessments of the potential for an overheated bearing condition. This has become a mandatory requirement for high-speed trains in Europe as identified in the European Technical Specification for Interoperability. This law states that "[the] equipment shall be able to detect a deterioration of the wheelset bearing health, either by monitoring its temperature, or its dynamic frequencies or some other suitable wheelset bearing health condition characteristic. A maintenance requirement shall be generated by this equipment and indicate a need for operational restrictions when necessary depending on the extent of the wheelset bearing deterioration. The detection system shall be located entirely onboard and diagnosis messages shall be communicated to the driver [6]."

There are two common methods used for onboard monitoring:

- Temperature detectors
- Accelerometers: oscillation sensors that detect abnormal vibrations

Aspects displayed to the operator are typically based on different levels of temperature readings, which will warrant the needed operational response (e.g., reduced speed, complete stop, etc.). Redundancy is incorporated to mitigate the possibility of false readings. Through research conducted to-date, at least one European operator stated a preference of monitoring oscillation accelerations versus temperature, as it can be used as a predictive tool to plan bearing maintenance [7].

2.4 Braking System Technologies

Braking systems on high-speed equipment have various effects on the design of the truck ranging from weight to induced forces/torques in the truck and suspension components. Vehicles today commonly employ the use of both friction and dynamic braking, with some rolling stock also equipped with eddy current brakes. Figure 1 shows the main types of brakes used in modern high-speed trains.

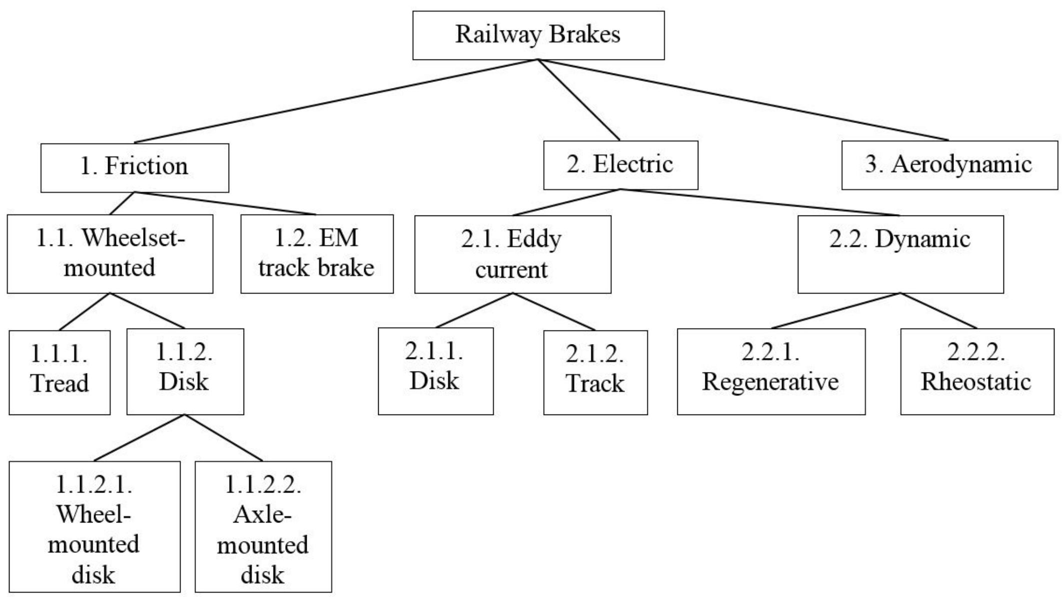

Figure 1. Braking Types Used in Modern High-Speed Trains

Friction Brakes

Friction brakes, which can be controlled pneumatically (i.e., via a trainlined brake pipe) or electrically (i.e., via a wired trainline as in Asian designs) are used on all high-speed trainsets, and can be comprised of disc brakes, tread brakes, and/or track brakes.

- Axle mounted brake disks (which are usually metal and either solid or ventilated). The brake calipers are usually mounted on the truck frame. The discs can be either inboard or outboard of the wheels. Outboard discs are frequently used on trucks with inboard axle bearings. A truck can have externally mounted brake disks and outboard bearings at the same time; for instance, Siemens SF 5000 series trucks have exterior bearings and wheel-mounted disks on the interior and on the exterior of each wheel. For heavy cars, there can be as many as three axle-mounted brake disks per axle (Bombardier FLEXX Load trucks).
- Cheek brakes, i.e., the brake surfaces (usually metal) are attached to the inside and outside of the wheel plates and calipers are installed on the truck frame and clamp around the wheels

A concern for outboard mounted disc brakes and also cheek brakes is how they interact with existing wayside heat sensing devices for monitoring bearing condition.

Tread brakes use shoes that, when activated, contact the tread of the wheel to retard the speed of the vehicle; these brakes are considered beneficial as they provide for cleaner running surfaces, which may improve the electrical contact (shunt) required for activating signaling systems. This cleaning effect may also remove unwanted contaminants that could reduce wheel-rail adhesion, but may reduce the beneficial effects of any intentional track lubricants and wheel-rail friction modifiers. For equipment that does not use tread brakes, it is not uncommon to see operators specify a requirement for the brake design to incorporate the use of tread cleaners. A disadvantage of tread brakes is that they tend to increase the rate of wear on the wheels, and may contribute to hollowing of the wheel treads.

Several types of rolling stock also use track brakes, also known as electromagnetic rail brakes, as part of the friction braking system. These brakes, when activated, press magnetically onto the rails, which provides the friction needed to reduce the speed of the equipment. The maintenance costs of using track brakes are high, however, as they require contact with the track. These brakes also tend to leave magnetic dust. One primary benefit is that they clean the rail and similar to tread brakes may assist in improving electrical contact. The cleaning effect may also remove unwanted contaminants that could reduce wheel-rail adhesion, but it may reduce the beneficial effects of any intentional track lubricants and wheel-rail friction modifiers. An advantage of track brakes is that they do not directly cause wear on the wheel treads. Track brakes are typically used only on electrically powered EMU vehicles, and therefore would not apply to any of the vehicles investigated in this study.

Electric Brakes

For powered vehicles such as EMU and DMU, dynamic braking is used, whereby the kinetic energy of the train is used to regenerate energy at the traction motors. This energy typically regenerates to the vehicle’s auxiliary power supply first; any excess energy can then be returned to the receptive overhead contact system (also known as regenerative braking), dissipated via onboard resistor grids if provided (also known as rheostatic braking), or addressed by an onboard power management supply (e.g., use of capacitors or other onboard energy storage devices). Dynamic braking has been the preferred method of braking, from a high-speed perspective, as it saves costs on having to replace friction brake material. It is commonly used in high-speed applications, with friction braking activated at lower speeds (e.g., before a station stop). An advantage of dynamic brakes is that they do not directly cause wear on the wheel treads. Since dynamic brakes are used only on powered vehicles with traction motors, they would not apply to any of the vehicles investigated in this study.

Another type of electric braking system that can be installed is the eddy current brake, which reduces the speed of the equipment via electromagnetic induction. Two types of eddy current brakes are the eddy current axle brake (i.e., seen on Japanese equipment) and the eddy current track brake (i.e., seen on European equipment). Several benefits of using such a brake are that it is contactless, independent of adhesion conditions on the wheel or rail, and reduces wear and tear on the friction brake equipment. However, a concern for the eddy current track brake is that each application heats the rail. In emergency conditions, this can result in an increase of 7 °F to 9 °F (4 °C to 5 °C) in rail temperature for a 1,312-foot (400 m) high-speed trainset. This may become problematic on ballasted track. The increased temperature increases longitudinal rail stress, which can cause sudden lateral movements of the track structure, especially in hot weather conditions. In addition, operators would have to factor in the use of eddy current brakes by understanding how many times it can be applied through a particular length of track, thereby possibly affecting the headways for their services [7]. Eddy current brakes are typically used only on electrically powered EMU vehicles, and therefore would not apply to any of the vehicles investigated in this study.

3. Model Development

3.1 Carbuilder Requests for Information

The data compiled for Sections 2.2.1 and 2.2.2 was first obtained via various internet sources. Industry input was then sought to assist with checking the compiled data, supplying the remaining information (i.e., those identified as "N/A") in the matrix, and providing more detailed data that would assist the project with the development of vehicle dynamics models for high-speed passenger trucks. Requests for information (refer to Appendix E) were sent out to industry stakeholders in early April 2013 that included:

- A cover letter providing a background to the project
- A snapshot of the master candidate list and the respective truck information spreadsheet tailored to the specific carbuilder
- A request for information required for vehicle model preparation
- Car and truck drawings: useful in providing vehicle dimensions, weights, suspension information, and assembly and attachment details
- Mass: Mass moments of inertia for roll, pitch, and yaw; center of gravities in x, y, z coordinates were needed for all components in a system that weigh over 100 pounds (45.3 kg), which include wheelsets, truck frames and associated subassemblies, traction motors, carbody, and carbody assemblies
- Car weights: Required for vehicle load conditions and include the total car weight (with trucks), the individual assembled truck weight, tare weight, and maximum loaded weight
- Characteristics of the primary and secondary suspensions: Includes force versus displacement and force versus velocity graphs, tilting algorithms (if applicable), stiffness of rubber bushings, stiffness of traction motor mountings, traction motor gear ratios, center plate diameter and friction coefficient, side bearing spacing and type, locations, and stiffness values of antiroll bars
- Characteristics of the airbag suspension: Includes airbag and reservoir volumes, working and operating pressures, airbag cross-sectional effective area, locations and sizes of all valves and orifices, piping lengths and inside diameters, vertical and shear stiffness, schematics of piping layout and function, setup procedures and intended operation, stiffness and static clearance of the emergency spring
- Truck information: Includes wheel back-to-back distance, flange thickness, height above low rail, and flangeway widths
- Wheel-rail profile and friction information: Needed to accurately model the wheel-rail contact geometry and to understand wheel-to-rail creepage/force characteristics on vehicle dynamics (especially for friction-modified track)
- A nondisclosure agreement form

In most cases, the responses were limited, as the information sought was proprietary to each specific vehicle/carbuilder. In some cases, data was supplied, but for vehicle types with a much higher operating speed than the target 125 mph (201 km/h) for this study. As a result, it was agreed with FRA to continue with the information already on hand and supplement it with data available through TTCI's model database. Therefore, the models developed are not representative of any one particular design, but are intended to represent "generic" design types for comparative analysis of one design to another.

3.2 Selection of Trucks and Model Criteria

TTCI and Parsons Brinckerhoff selected five truck design types to evaluate for safety and dynamic performance including passenger comfort ride quality. The designs were differentiated primarily by the suspension type. Mathematical models were developed in NUCARS® by using data available and supplemented through TTCI's database.

- Radial arm suspension
- Equalizer beam suspension
- Rubber chevron suspension
- Conical spring suspension
- Journal spring suspension

The models were evaluated over static and dynamic regimes to compare the strengths and limitations of each design for both high-speed and low-speed trackworthiness. In addition to specifications developed to evaluate passenger vehicle dynamic performance, regimes were chosen based on the Association of American Railroads' (AAR) Manual of Standards and Recommended Practices (MSRP), Section C, Part II, Standard M-1001, Chapter 11 [2].

3.3 Vehicle Performance Modeling and Evaluation Criteria

TTCI modeled several dynamic simulation regimes. Although some of the regimes are not specific to passenger car operating environments (such as AAR Chapter 11), they are rigorous dynamic scenarios that allow a comparative analysis to be made between the five truck types detailed in this study.

3.4 Carbody Models

The vehicle models were not based on any particular manufacturer's design; generic models of the carbody, secondary suspension and truck design were developed. Two carbody models were developed based on the Passenger Rail Investment and Improvement Act (PRIIA) of 2008 Specification 4.3.1 Dimensions, Weights, and Under Car Clearance for both the single-level and bi-level passenger railcars shown in Table 3 [61] [62].

Table 3. PRIIA Carbody Specification for NUCARS® Models

	Single-Level	Bi-Level
Weight (Coach Car)	104,000 lb.	150,000 lb.
Length (over coupler pulling faces)	85 ft. 0 in.	85 ft. 0 in.
Height (maximum) (ATOR)	14 ft. 6 in.	16 ft. 2 in.
Carbody Width (excluding side handholds)	10 ft. 2 in.	10 ft. 2 in.
Truck Centers	59 ft. 6 in.	59 ft. 6 in.
Upper floor height (ATOR)	N/A	8 ft. 8.5 in.
Lower floor height/Single-level floor height (ATOR)	4 ft. 3 in.	1 ft. 6 in.
Roll Inertia (lb-in-sec2)	4.216E+05	1.102E+06

	Single-Level	Bi-Level
Pitch Inertia (lb-in-sec2)	1.435E+07	2.521E+07
Yaw Inertia (lb-in-sec2)	1.436E+07	2.485E+07

Coach car weights were used rather than cab/baggage car or café/lounge car as the more conservative weight representation. The masses and dimensional limits were used to estimate mass moments of inertia for the mathematical models. These were calculated based on assuming a uniform mass distribution of the carbody. Figure 2 and Figure 3 show conceptual drawings of the single-level and bi-level carbodies, respectively.

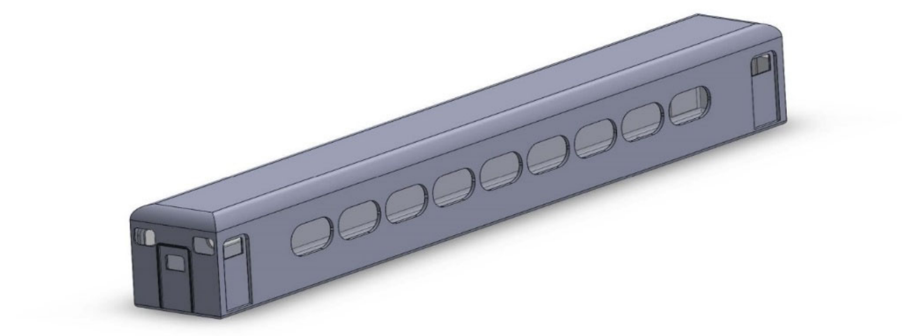

Figure 2. Conceptual Illustration of the Single-Level Carbody

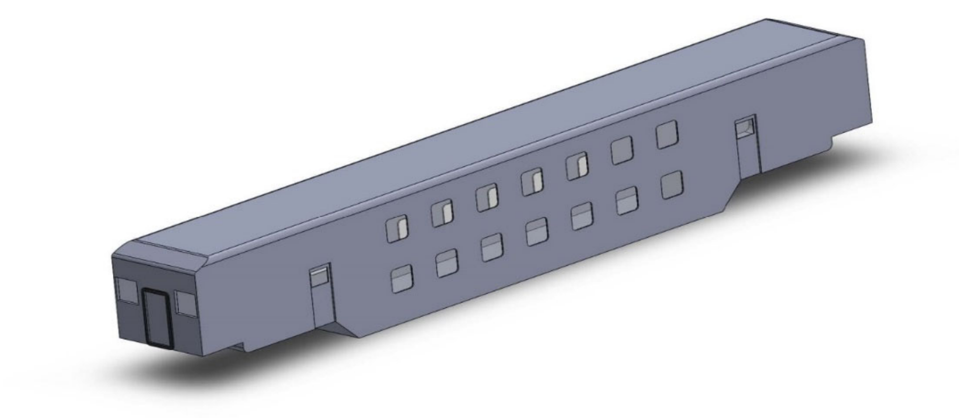

Figure 3. Conceptual Illustration of the Bi-level Carbody

3.4.1 Secondary Suspension

Because the focus of this study was on the trucks, the secondary suspension was held constant for all five truck types. The carbody secondary suspension was provided by air springs located at each end of the bolster. Simulations were initially conducted using a four-point air spring system, with no connecting pipes between the four individual systems. An anti-roll bar was also included to provide additional roll stiffness. Figure 4 is an illustration of the air spring system and vertical air spring model [63].

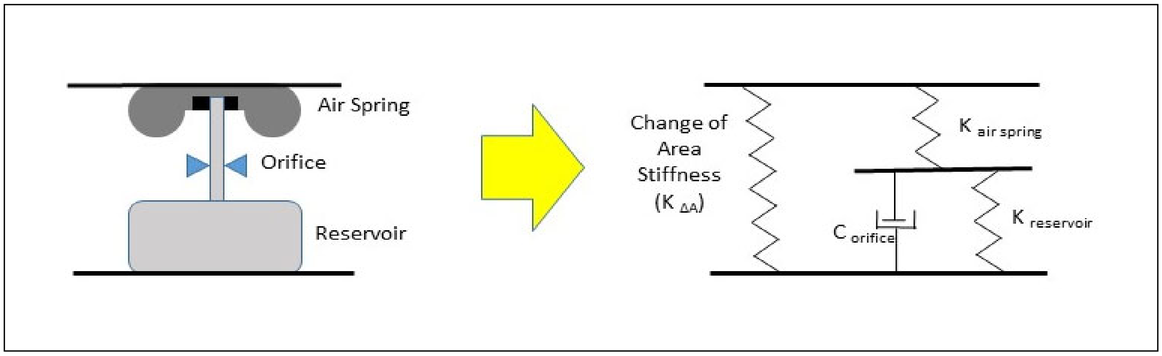

Figure 4. Air Spring System and Vertical Air Spring Model

Figure 5 illustrates how the lateral suspension is represented in the NUCARS® model, with both a frequency dependent lateral, or dynamic shearing stiffness (e.g., a series spring/damper) and a quasi-static lateral stiffness. The frequency dependent lateral stiffness can be measured from modal frequency tests, whereas the quasi-static stiffness can be measured by applying a force and measuring the displacement.

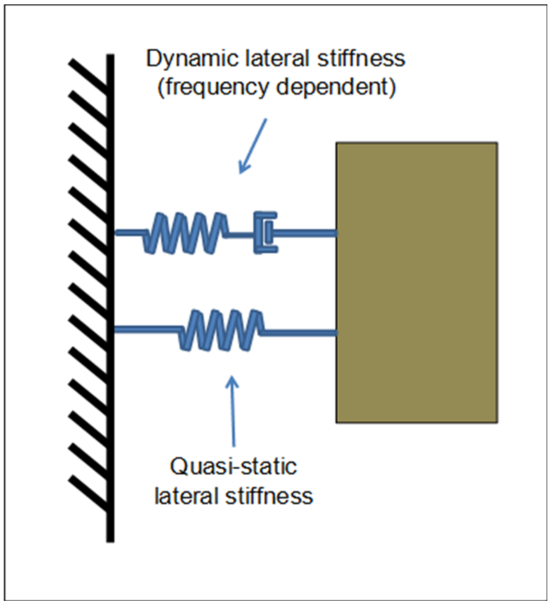

Figure 5. Lateral Air Spring Model

Damping in the air spring system is provided by an orifice between the air spring and the reservoir. The damping is nonlinear based on the air pressure and flow rate through the orifice. Figure 6 shows the damping rates for the two different carbodies. The rates are different because the different carbody weights result in different operating pressures [64].

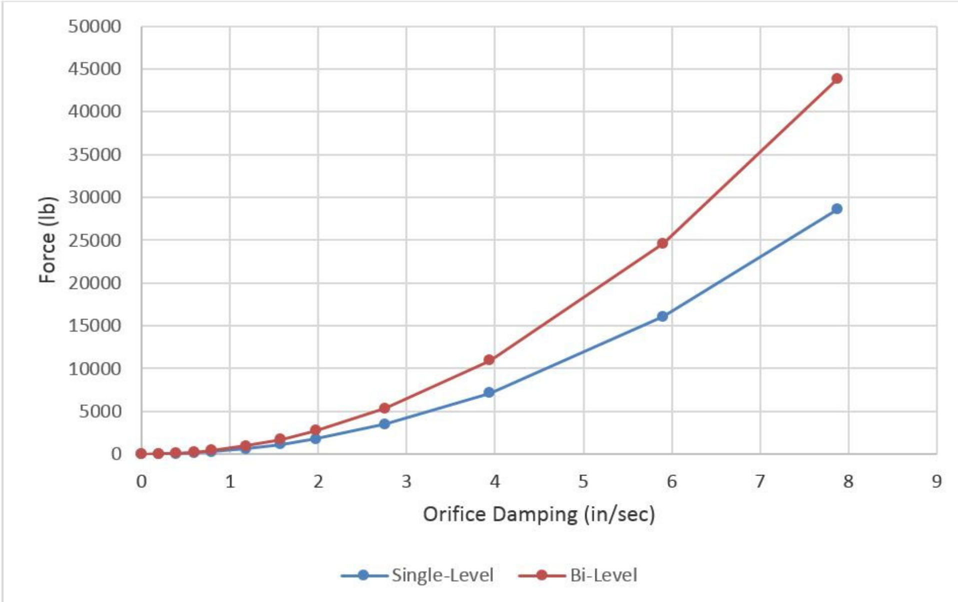

Figure 6. Air Spring Orifice Vertical Damping

To improve wheel load equalization between trucks on twisted track, some actual passenger car air spring systems include connecting pipes between the two air springs on a truck. This has the effect of significantly reducing the quasi-static roll stiffness for the truck(s) with the connecting pipe. The connecting pipe then provides some dynamic roll damping, dependent on the connecting pipe diameter. Cars with connected air springs on both trucks are referred to as having two-point suspensions. Cars with connected air springs on only one truck are referred to as having a three-point suspension. Three-point air spring suspensions must be tested and modeled in both leading and trailing operation, because the difference in roll stiffness between the two ends causes the curving performance to be dependent on the direction of operation.

Other variations in air spring system design can also affect vehicle dynamic response. An accurate representation of each of these parameters is required to model them correctly:

- Reservoirs separated from the airbag by a connecting pipe: pipe length and volume can cause the mass of air moving in the pipe to alter the dynamic response of the system
- Location of interconnection pipes on two-point and three-point suspensions: between air bags, between air reservoirs, or between one air bag and the opposite reservoir
- Air springs on one truck sharing a reservoir instead of using an interconnection pipe
- Orifice diameter: affects damping rate, some suspension systems eliminate hydraulic dampers by providing all damping from the orifices
- Flexible orifices: flexibility allows the orifice diameter to change with flow rate, altering the damping characteristics
- Change of area stiffness: this is affected by the physical design of the air bag and can be negative in some designs
- Bolsterless truck designs, which have air springs connected directly between the carbody and the truck frame. Truck rotation is accommodated by longitudinal shear of the air

bags: this results in truck rotational resistance that is dependent on the shear stiffness characteristics of the air spring system instead of friction at the centerplate and/or side bearings

- Shape of the airbag and its housing can be used to alter the longitudinal and lateral shear stiffness properties

In many cases, stiffness and damping characteristics can only be accurately determined by physical tests. Numerous combinations of the above variations are possible. Therefore, to keep the modeling matrix to a manageable size, none of the above variations were simulated for this project, although all are possible using NUCARS®.

3.5 Primary Suspension — Truck Design

3.5.1 Radial Arm Suspension

The radial arm running gear is modeled as a rigid H-frame truck with a radial arm primary suspension, as shown in Figure 7. In this arrangement, the axle box is situated at the end of a radial arm pivoted to the truck frame. Typically, a coil spring (primary suspension) is situated above the axle box between the axle box and truck frame. Longitudinal and lateral stiffness is provided by a rubber bush at the trailing arm pivot. This truck uses a bolster with a center pin arrangement and side bearings for truck rotation.

This type of suspension system yields relatively high primary longitudinal and yaw stiffness, which is beneficial for high-speed stability while reducing curving performance. Additionally, due to the rotation of the radial arm connection to the truck frame, the primary suspension moves in a circular arc motion rather than true vertical motion; this can negatively impact the truck's ability to negotiate track warp. In addition, the vertical motions cause the axles to move longitudinally, which induces dynamic small variations in axle alignment.

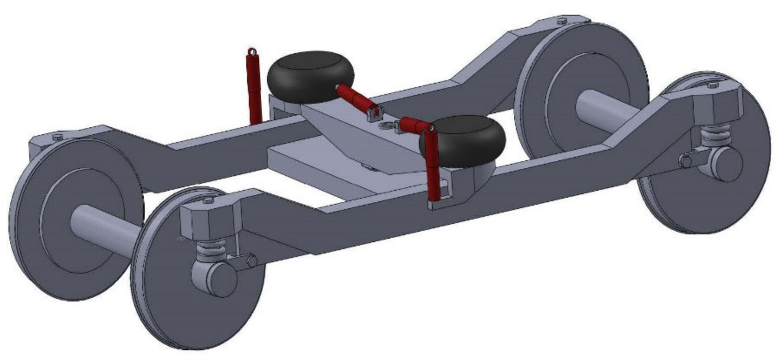

Figure 7. General Arrangement of the Radial Arm Suspension Design

3.5.2 Equalizer Beam Suspension

Equalizer beam trucks have journal boxes which are free to move vertically in pedestal guides on the H-frame. The ends of the equalizer beam sit atop the axle journal boxes, and the truck frame is supported on the equalizer beam by the primary coil springs (Figure 8). This truck uses a bolster with a center pin arrangement and side bearings for truck rotation.

Equalizer beam trucks generally provide good wheel load equalization even with relatively stiff vertical primary suspension. The primary suspension is provided on each side of the truck by two coil spring arrangements between the equalizer beam and the truck frame along each particular side. No primary damping is provided. Longitudinal and lateral restraint of the wheelset is provided by the pedestal guides.

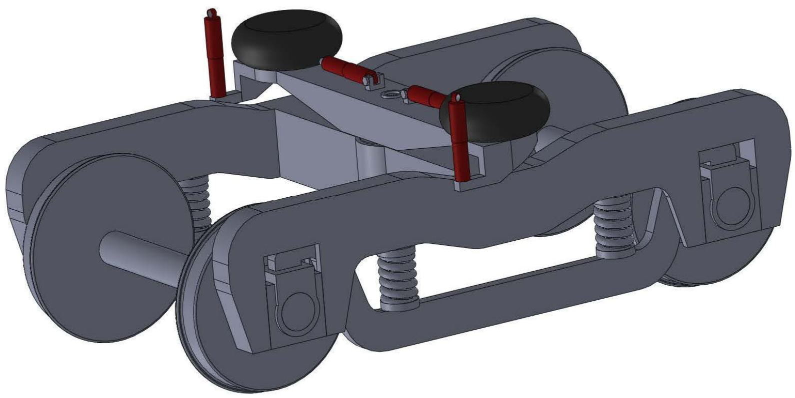

Figure 8. General Arrangement of the Equalizer Beam Truck Design

3.5.3 Rubber Chevron

The rubber chevron truck type uses an H-frame with a metal-rubber chevron primary suspension, illustrated in Figure 9. The primary spring consists of a set of rubber chevrons contained by metal plates. Each axle box has one pair of springs mounted at an angle. Vertical and lateral stiffness are provided by the shearing of the rubber between the metal plates. Longitudinal stiffness is provided by compression of the rubber normal to its surface. This suspension type has very high longitudinal and yaw stiffness.

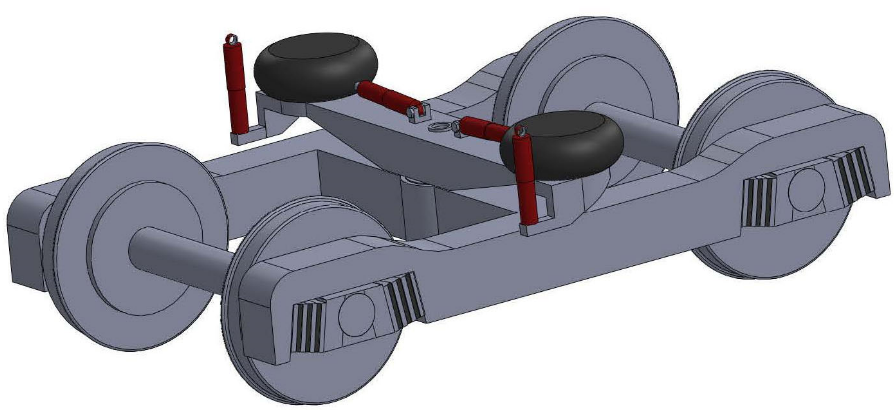

Figure 9. General Arrangement of the Rubber Chevron Truck Design

3.5.4 Journal Spring Suspension

Figure 10 shows an illustration of a journal spring truck design. Journal spring trucks consist of an H-frame suspended by pairs of coil springs located at each axle box, which provide the primary vertical stiffness. Nested within each coil spring is a rubber column damping element, which has freedom to slide vertically; consequently, this provides friction damping in the vertical direction. The compliance of the rubber also provides longitudinal and lateral primary suspension stiffness. This truck has a relatively stiff primary longitudinal and yaw stiffness.

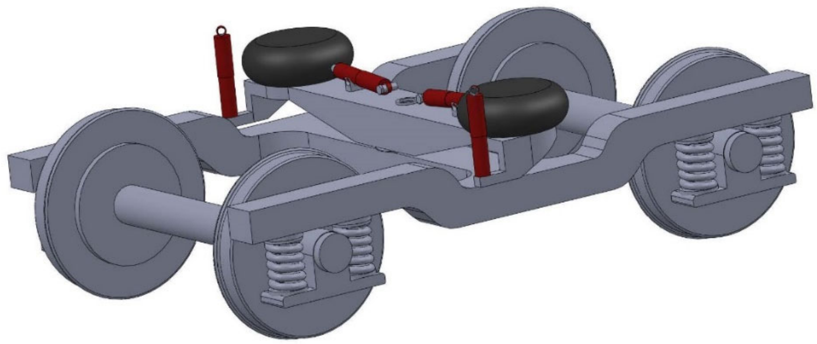

Figure 10. General Arrangement of the Journal Spring Truck Design

3.5.5 Conical Spring Suspension

Figure 11 shows an illustration of a conical spring truck design. This truck type consists of an H-frame with conical spring primary suspension. The conical spring is a rubber element consisting of conjoined rubber rings of varying diameter. Like the journal spring suspension, these are typically situated in pairs at each axle box. The rubber provides both stiffness and damping in the longitudinal, lateral, and vertical directions. Suspension characteristics can be customized by varying the size and shape of the rubber rings.

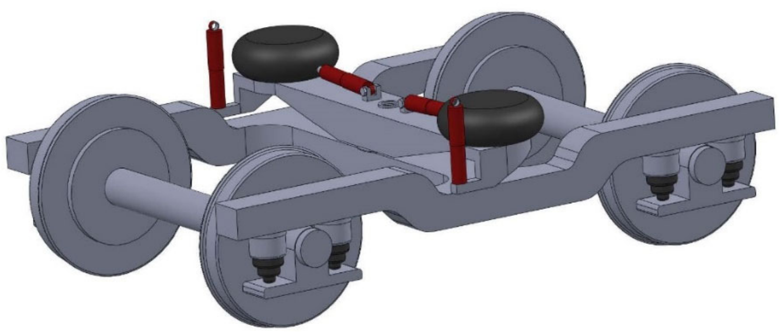

Figure 11. General Arrangement of the Conical Spring Truck Design

3.5.6 Primary Suspension Parameters

Table 4 shows the main dimensions and spring stiffnesses used for the different generic trucks. These data were adapted from published data and TTCI's experience in testing and simulating a wide range of passenger vehicles. For simplicity, the same stiffness values were used for both the single-level and bi-level versions, and the vertical air bag suspension characteristics were adjusted to achieve realistic rigid body modal frequencies (Table 5) for the two carbodies equipped with two of the different trucks. A NUCARS® eigenvalue analysis was performed to determine the modal frequencies. Figure 12 illustrates the five different rigid modes. Copies of the NUCARS® system files (SYS files) for each carbody and truck combination are included in Appendix H.

Table 4. Truck Characteristics

	Radial Arm	Equalizer Beam	Rubber Chevron	Journal Spring	Conical Spring
Axle Spacing (ft)	8.5	8.5	8.5	8.5	7.87
Longitudinal Stiffness (lb/in)	1.7E5	16,000 (1)	129,477	248,000	26,266
Lateral Stiffness (lb/in)	5.2E4	-	20,556	47,013	11,420
Vertical Stiffness (lb/in)	6,079	10,250	17,136	7,000	5,710
Yaw Stiffness (lb-in/rad)	-	-	180,025,000	-	-
Lateral Damping (lb-sec/in)	50	50	50	50	50
Vertical Damping (lb-sec/in)	25	25	25	25	25
Eff. Air Spring Vertical Stiffness (lb/in) - Single-Level	1,828.13	1,828.13	1,828.13	1,828.13	1,828.13
Eff. Air Spring Vertical Stiffness (lb/in) - Bi-Level	2,799.01	2,799.01	2,799.01	2,799.01	2,799.01
Air Spring Quasi-static Lateral Stiffness (lb/in)	425	425	425	425	425
Anti-Roll Bar Stiffness (lb-in/rad)	3.00E+07	3.00E+07	3.00E+07	3.00E+07	3.00E+07
Air Spring Orifice Diameter (in)	0.59	0.59	0.59	0.59	0.59

Notes: Within pedestal jaw clearance, becomes much stiffer when clearance is exceeded.

Table 5. Rigid Body Modal Frequencies

Truck	Long	Lower Center Roll	Upper Center Roll	Pitch	Bounce	Yaw
Radial Arm Bi-Level	0.2598	0.5923	2.767	1.4304	1.1801	
Radial Arm Bi-Level, Reduced Roll Inertia		0.6166	2.799	1.4304	1.1801	2.5873
Radial Arm Single-Level	0.3145	0.969	3.1182	1.9074	1.5825	
Radial Single-Level, Reduced Vertical, Including Roll Inertia	0.3145	0.6931	2.8438	1.6226	1.3511	2.4922
Equalizer Beam Bi-Level	0.2546	0.5688	2.6701	1.2597	1.0622	
Equalizer Beam Single-Level	0.3054	0.9105	3.0014	1.6617	1.3947	
Equalizer Single-Level, Reduced Vertical	0.3053	0.6385	2.9195	1.2169	1.0206	2.4804

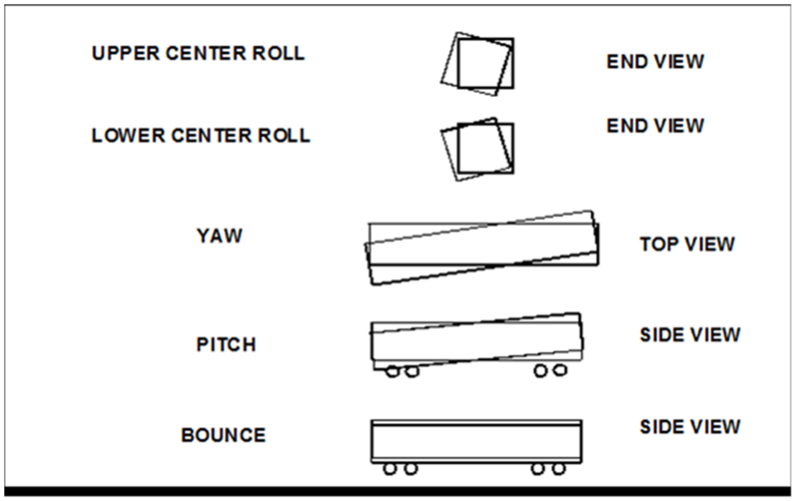

Figure 12. Rigid Body Modes

3.6 Wheel and Rail Profiles

To objectively compare the performance of each truck, wheel and rail profiles were held constant throughout the simulations. The PRIIA specifications state that car designs shall use wheels with a 1:40 taper [61] [62]. Therefore, the American Public Transit Association (APTA) 340 with 53 3/16-inch back-to-back spacing was chosen for the wheel profile. Theoretical (new) 136 lb. rail with 10-inch crown radius and 1:40 cant was chosen. The wheel and rail interaction on tangent track is detailed in the upper image of Figure 13, and the lower image of Figure 13 shows lateral shift due to curving.

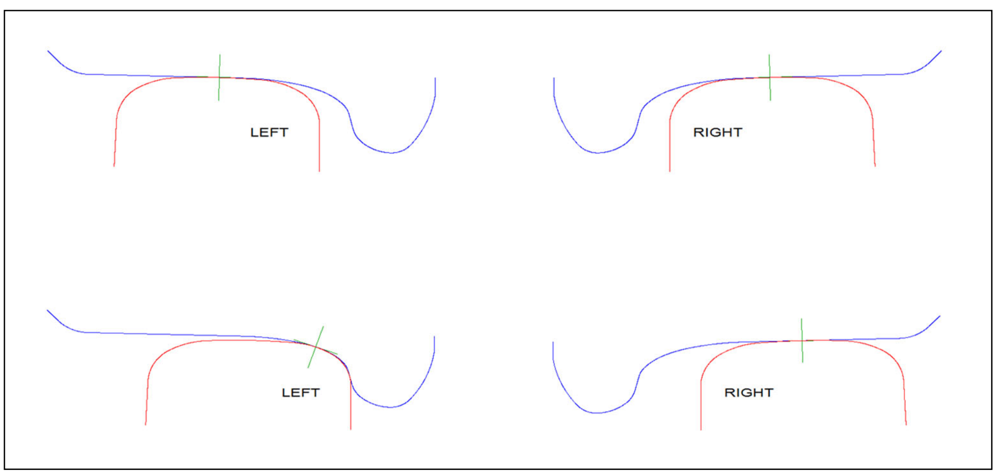

Figure 13. APTA 340 Wheel on the American Railway Engineering and Maintenance-of-Way Association (AREMA) 136 lb. Rail

3.7 AAR Chapter 11 Simulation Regimes

To provide realistic inputs, the AAR Chapter 11 simulation used measured track geometry data from the various Chapter 11 test zones (i.e., wheel-rail mechanism [WRM] loop, Precision Test Track [PTT], and Railroad Test Track [RTT]) located at the Transportation Technology Center

(TTC). All simulations were conducted using the APTA 340-wheel profile and AREMA 136 lb. rail (Figure 13).

3.7.1 Wheel-Rail Mechanism Loop

Figure 14 shows the WRM loop, which is used for vehicle curving tests. It contains 3-, 4-, 5-, 7.5-, 10-, and 12-degree curves. The curves used for the simulations were the 7.5-, 12-, and 10-degree curves on the west side of the loop. The 10-degree curve of the WRM loop has a bypass track. The south end of the bypass track has a spiral that is 88-feet long. This spiral is called the limiting spiral and is used for AAR certification tests. The dynamic curve test section is located in the body of the curve of the bypass track. The dynamic curve contains five cusp-shaped profile deviations having 39-foot wavelength and 0.5-inch amplitude. The outside rail contains five alignment deviations having 39-foot wavelength and 1.0-inch amplitude. The alignment deviations are positioned so that the location of wide gage corresponds to the location of the dip in the outside rail. Figure 15 shows the measured track geometry of the WRM loop in the clockwise direction for the 7.5-degree, 12-degree, and 10-degree curves. The figure shows, from top to bottom, curvature, superelevation, left rail lateral alignment, left rail vertical profile, right rail lateral alignment, and right rail vertical profile respectively. Figure 16 shows the track geometry measurements for the 10-degree bypass including the limiting spiral and dynamic curve, also measured in the clockwise direction.

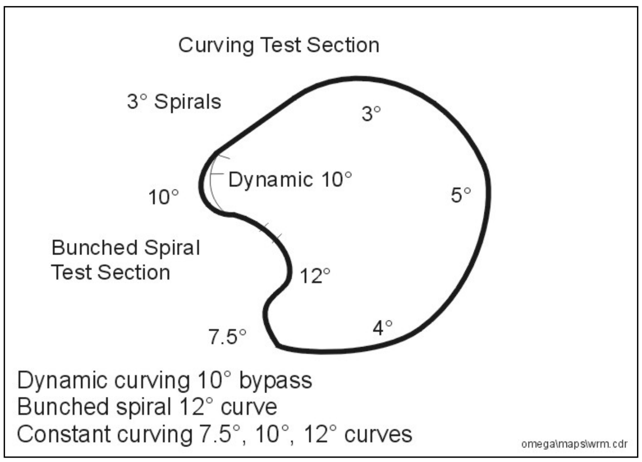

Figure 14. WRM Loop

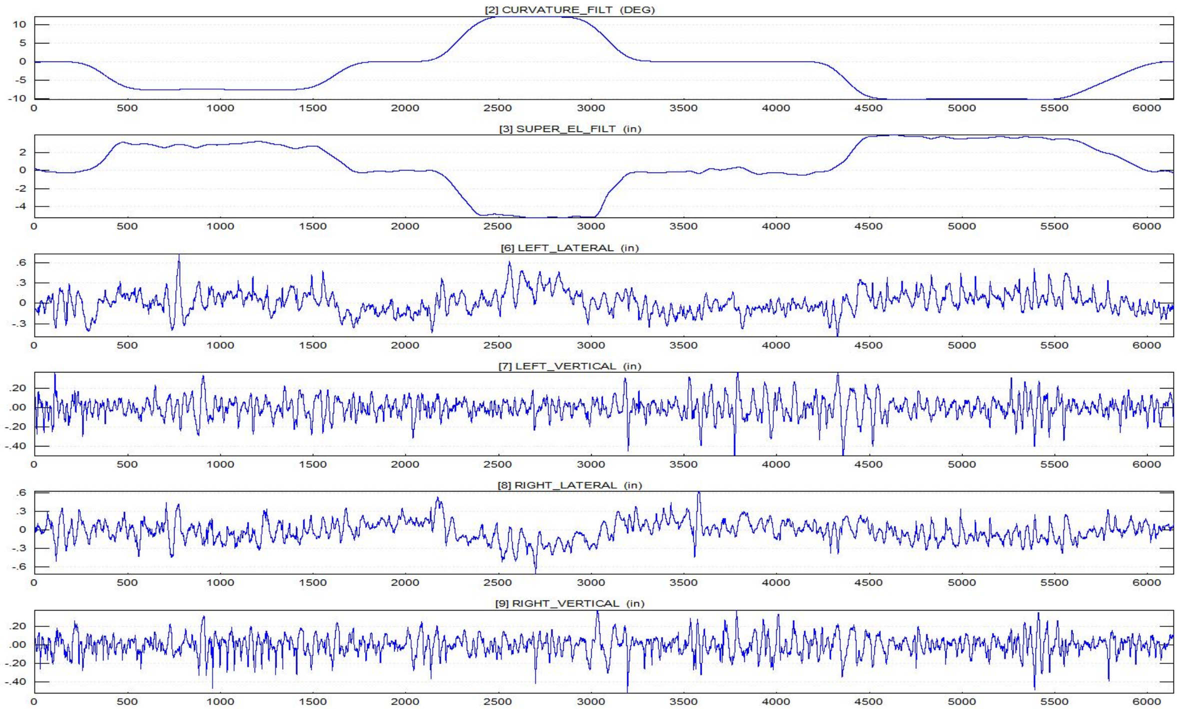

Figure 15. Measured Constant Curving Track Geometry

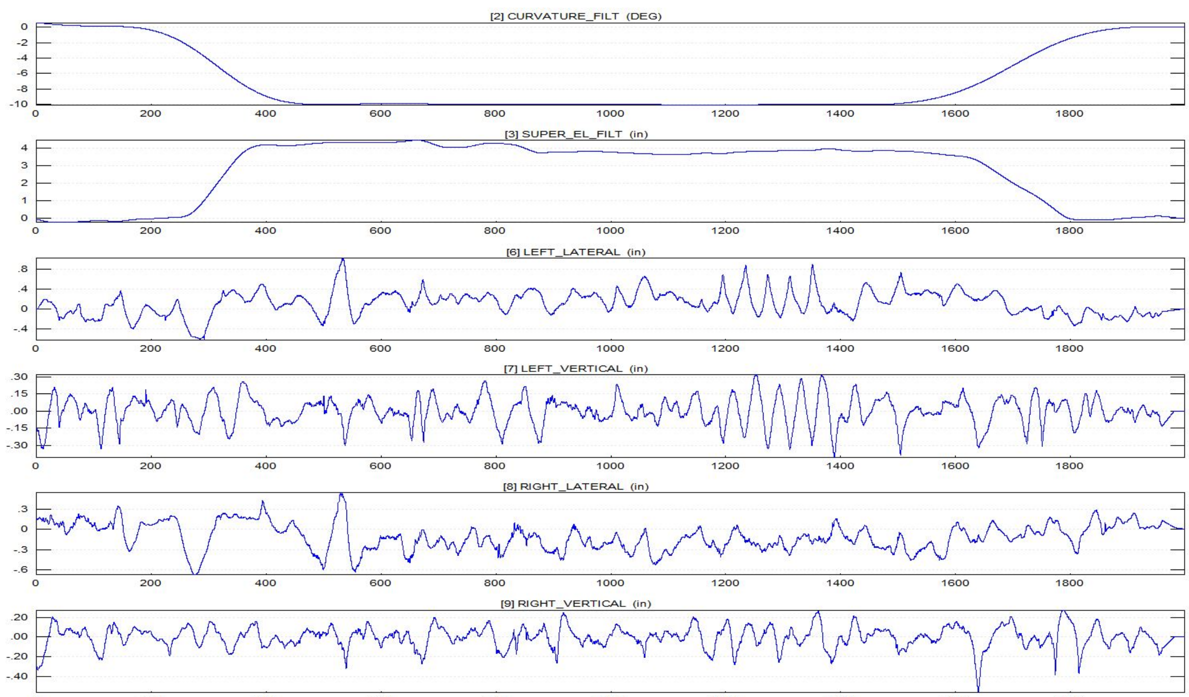

Figure 16. Measured Dynamic Curve and Limiting Spiral Track Geometry

3.7.2 Precision Test Track

The PTT includes the twist and roll, pitch and bounce, and yaw and sway test zones. The twist and roll test section uses 10 staggered cusp-shaped perturbations having 39-foot wavelength and

0.75-inch amplitude. The perturbations on the left and right rails are offset 19.5 feet to excite the twist and roll motions of the vehicle. Simulation speeds were from 10 mph to 105 mph in 5 mph (16 km/h to 169 km/h in 8 km/h) increments.

The pitch and bounce test section uses 10 parallel cusp-shaped perturbations having 39-foot wavelength and 0.75-inch amplitude. The perturbations on the left and right rails are aligned to excite the pitch and bounce motions of the vehicle. Simulation speeds were from 10 mph to 105 mph in 5 mph (16 km/h to 169 km/h in 8 km/h) increments.

The yaw and sway test section uses five aligned, sine shaped perturbations having 39-foot wavelength and 1-inch amplitude on a section with 1-inch wide gage. The zone excites the yaw and upper center roll motions of the vehicle. Simulation speeds were from 10 mph to 105 mph in 5 mph (16 km/h to 169 km/h in 8 km/h) increments.

Figure 17 through Figure 19 show the PTT track geometry data used for input into the NUCARS® simulations.

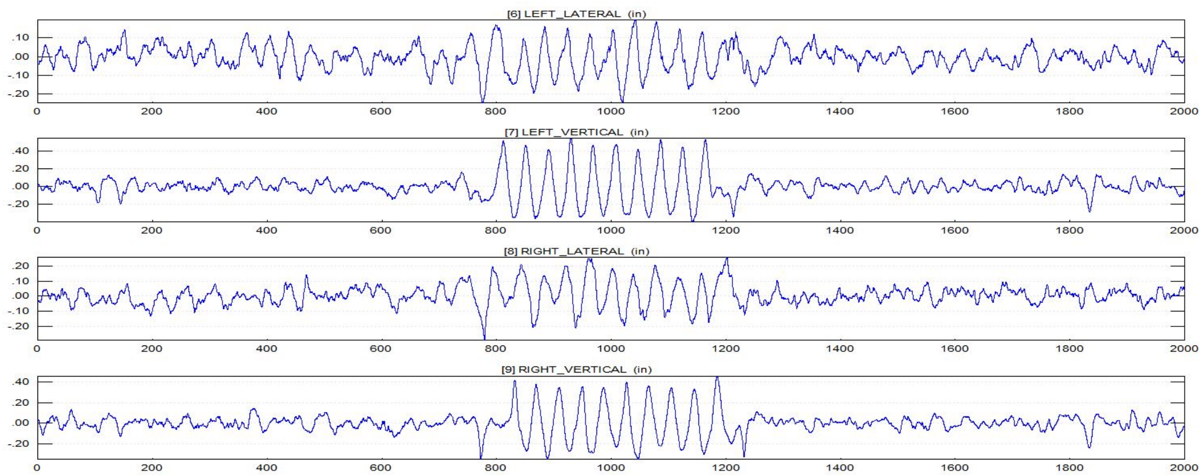

Figure 17. Measured Twist and Roll Track Geometry

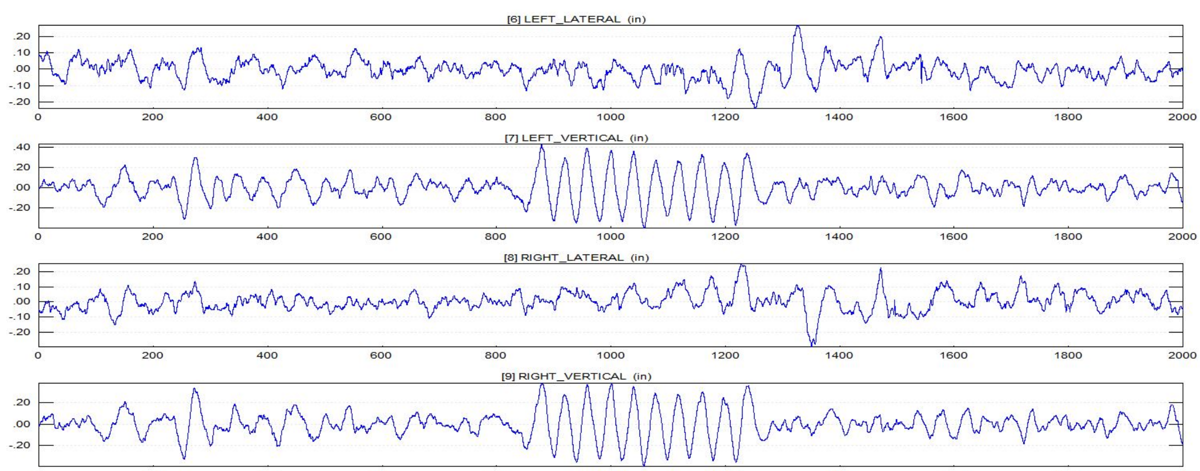

Figure 18. Measured Pitch and Bounce Track Geometry

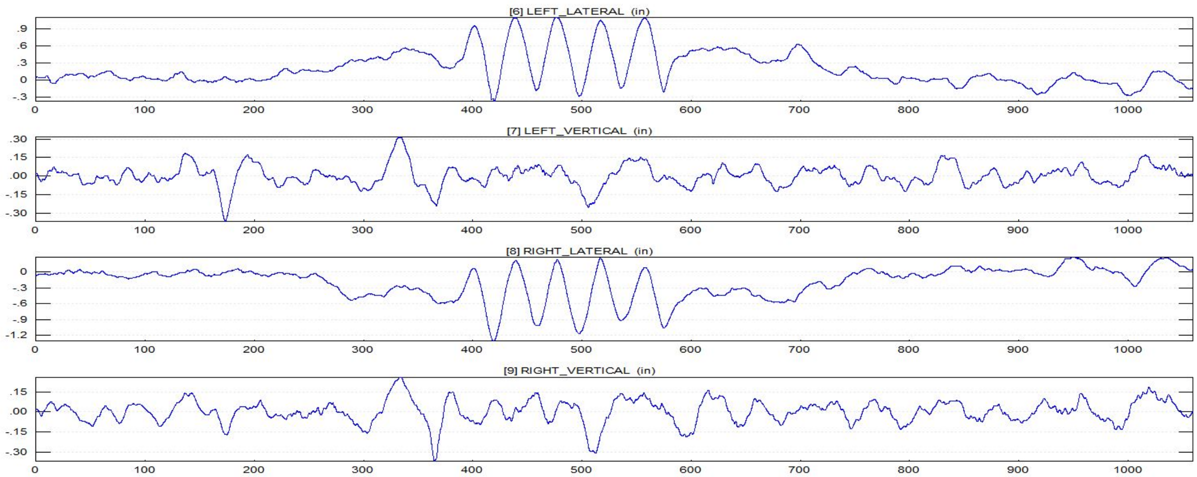

Figure 19. Measured Yaw and Sway Track Geometry

3.7.3 Railroad Test Track

The RTT (Figure 20) was used for high-speed stability (hunting) simulations. Figure 21 shows the measured track geometry input data.

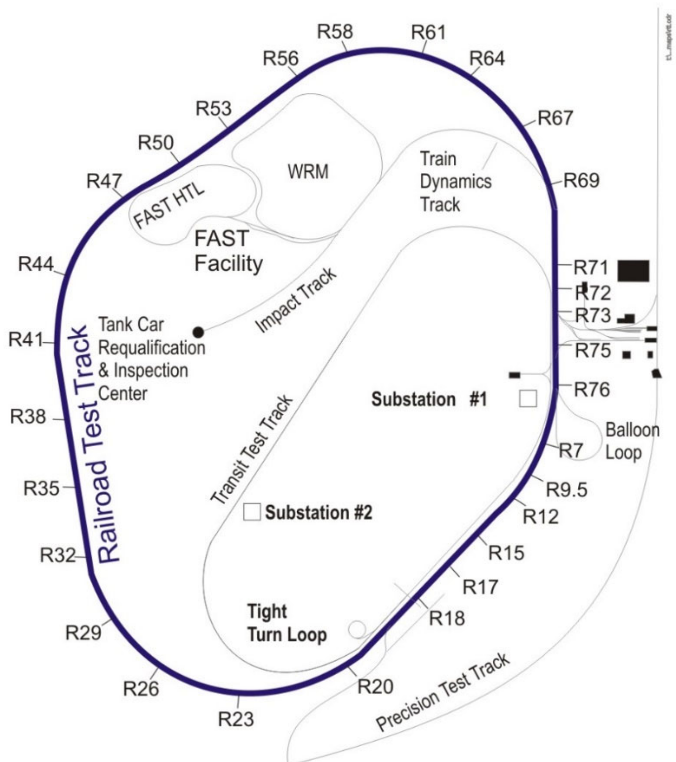

Figure 20. RTT Track

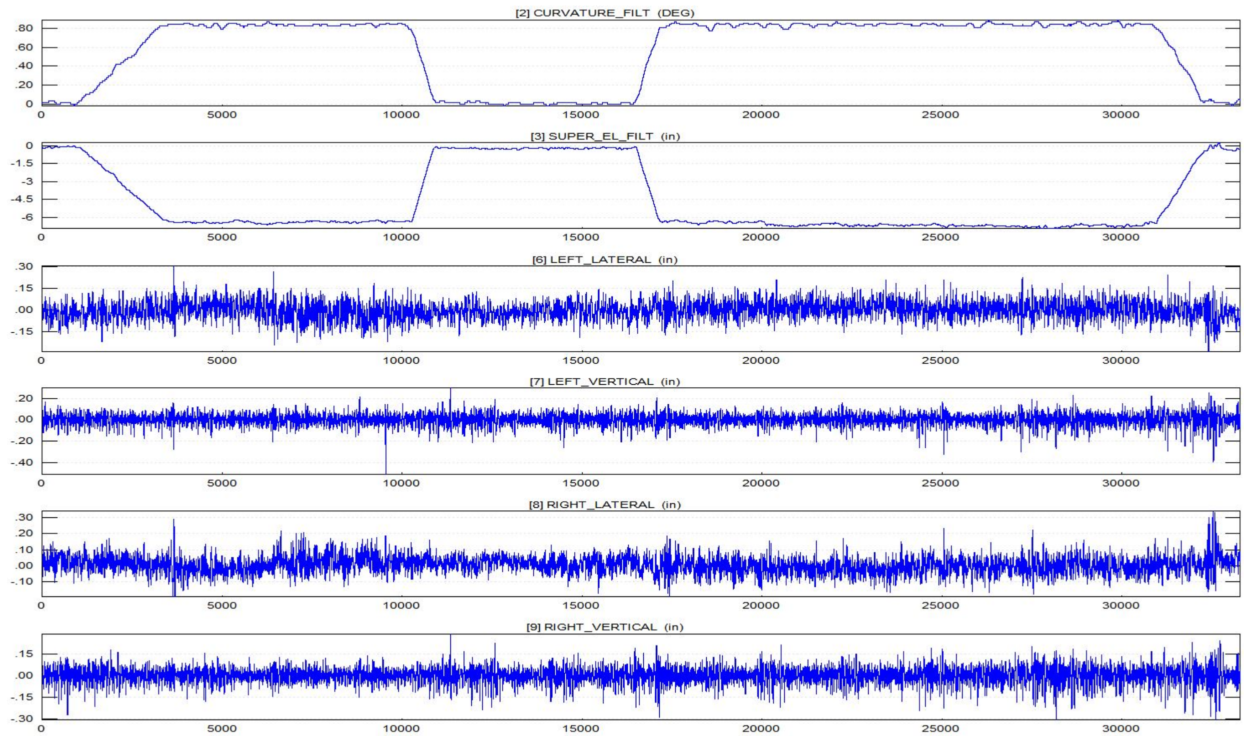

Figure 21. Measured RTT Track Geometry

3.8 Evaluation Criteria

Results from the simulations were compared to AAR Chapter 11, and the Title 49 Code of Federal Regulations (CFR) § 213.333 performance criteria [65]. Table 6 shows the criteria set forth in Chapter 11. Table 7 shows the criteria set forth in 49 CFR § 213.333.

Table 6. AAR Chapter 11 Evaluation Criteria

Test Regime	Limiting Value	Analysis Parameters
Constant Curve	95th Percentile Maximum Wheel L/V Ratio	0.8
	95th Percentile Maximum Axle Sum L/V Ratio	1.5
Standard Spiral Negotiation	Minimum Vertical Wheel Load	10%
	Maximum Wheel L/V Ratio	1.0
	Maximum Axle Sum L/V Ratio	1.5
Bunched Spiral Negotiation	Minimum Vertical Wheel Load	10%
	Maximum Wheel L/V Ratio	1.0
	Maximum Axle Sum L/V Ratio	1.5
Dynamic Curving	Maximum Roll Angle (Peak-to-Peak)	0.1 radian (6 degrees)
	Minimum Vertical Wheel Load	10%
	Maximum Wheel L/V Ratio	1.0
	Maximum Axle Sum L/V Ratio	1.5
Limited Spiral Negotiation	Minimum Vertical Wheel Load	10%
	Maximum Wheel L/V Ratio	1.0
	Maximum Axle Sum L/V Ratio	1.5
Twist and Roll	Maximum Roll Angle (Peak-to-Peak)	0.1 radian (6 degrees)
	Maximum Axle Sum L/V Ratio	1.5
	Minimum Vertical Wheel Load	10%
	Dynamic Augment Acceleration (g)	1.0
Pitch and Bounce	Minimum Vertical Wheel Load	10%
	Dynamic Augment Acceleration (g)	1.0
	Loaded Spring Capacity Maximum	95%
Yaw and Sway	Maximum Truck Side L/V Ratio	0.6
	Maximum Axle Sum L/V Ratio	1.5

Table 7. 49 CFR § 213.333 Performance Criteria

Wheel Rail Forces[1]			
Parameters	**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% of the static vertical wheel load for 5 or more continuous feet. The static vertical wheel load is defined as the load that the wheel would carry when stationary on level track.
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 safe limit calculated for the wheel flange angle (δ) for 5 or more continuous feet.
Net Axle Lateral L/V Ratio	$\leq 0.4 + \frac{5.0}{V_a}$	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% of the static vertical load that the axle exerts on the track for 5 or more continuous feet.
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[2]			
Parameters	**Passenger Cars**	**Other Vehicles**	**Requirements**
Carbody Lateral (Transient)	≤0.65g peak-to-peak 1 sec window[3] excludes peaks < 50 msec	≤0.75g 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 1-second time period, excluding any peak lasting less than 50 milliseconds, shall not exceed 0.65g and 0.75g for passenger cars and other vehicles respecively.
Carbody Lateral (Sustained Oscillatory)	≤0.10g RMS_t[4] 4 sec window[3] 4 sec sustained	≤0.12g RMS_t[4] 4 sec window[3] 4 sec sustained	Sustained oscillatory lateral acceleration for 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 are to be determined over a sliding 4-second window with linear trend removed and shall be sustained for more than 4 seconds
Carbody Vertical (Transient)	≤1.0g peak-to-peak 1 sec window[3] excludes peaks < 50 msec	≤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 1-second time period, excluding any peak lasting less than 50 milliseconds, shall not exceed 1.0g and 1.25g for passenger cars and other vehicles respecively.
Carbody Vertical (Sustained Oscillatory)	≤0.25g RMS_t[4] 4 sec window[3] 4 sec sustained	≤0.25g RMS_t[4] 4 sec window[3] 4 sec sustained	Sustained oscillatory vertical acceleration for the carbody shall not exceed the prescribed (root mean squared) safety limits of 0.25g. Root mean squared values are to 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 Acceleration	≤0.30g RMS_t[4]	2 sec window[3] 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 are to 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]RMSt = RMS (root-mean-square) 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).

3.9 Minimally Compliant Analytical Track (MCAT)

The MCAT specifications in Appendix D to 49 CFR Part 213 [67] define a set of simulations used to qualify a vehicle-track system for use in service as required for vehicles operating at Class 7 speeds or higher. The track is theoretical and consists of nine connected segments, each with a unique perturbation of varying wavelength and amplitude. Track curvature and cant deficiency were also varied, as well as track gage. These track variations were constructed as inputs into NUCARS® and used to test the five truck types.

3.9.1 MCAT Layout

As shown in Figure 22, the MCAT input consists of nine segments (labeled as Table D1 in Appendix D to 49 CFR Part 213) for a total of 9,500 feet in length. Each perturbation is unique and is designed to test a specific track condition. All segments are 1,000 feet long with the exception of segment 4, which is 1,500 feet.

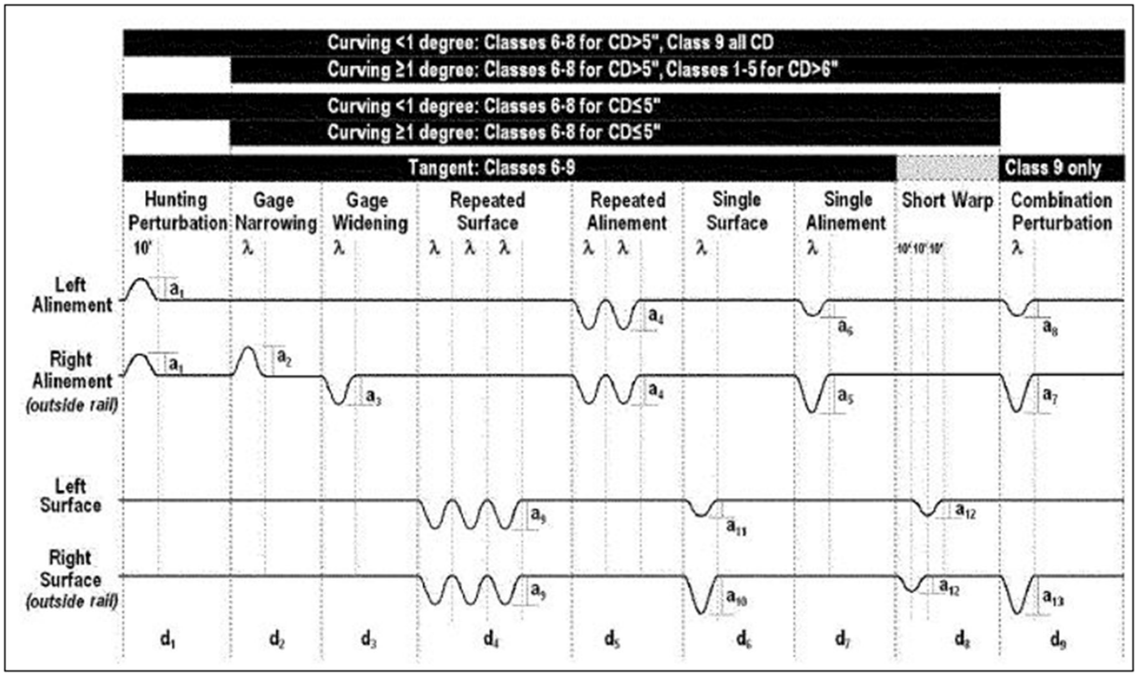

TABLE 1 OF APPENDIX D TO PART 213 MINIMUM LENGTHS OF MCAT SEGMENTS

Distances (ft)								
d_1	d_2	d_3	d_4	d_5	d_6	d_7	d_8	d_9
1000	1000	1000	1500	1000	1000	1000	1000	1000

Figure 22. Appendix D to 49 CFR Part 213 Basic MCAT Layout

3.10 MCAT Run Matrix

Based on the scope of this study, FRA Class 7 speeds were chosen for the simulations. Simulations were conducted for both tangent and curved track. Tangent cases were run using 56.5-inch track gage, while curving runs required both 56.5- and 57.0-inch gage. Table 8 shows the required values of curvature and cant deficiency for Class 7 speeds of 115, 120, and 125 mph (185, 193, and 169 km/h). Curvature and superelevation variations were run for cant deficiencies of 3, 4, and 5 inches.

Table 9 and Table 10 shows the required values of wavelength and amplitude for simulations on tangent and curved track, respectively.

Table 8. Curvature and Cant Deficiency for Class 7 MCAT Simulations

Table 2 of Appendix D to Part 213
Degree of Curvature for Use in MCAT Simulations (Track Classes 2 through 9)

		Tangent	Cant Deficiency (inches)								
			3	4	5	6	7	8	9		
Passenger	m.p.h.	Degree of curvature used in simulations								m.p.h.	Freight
Class 2	20						46.4	50.0	53.6	20	Class 2
	25						29.7	32.0	34.3	25	
	30						20.6	22.2	23.8	30	Class 3
Class 3	35						15.2	16.3	17.5	35	
	40						11.6	12.5	13.4	40	
	45						9.17	9.88	10.6	45	Class 4
	50						7.43	8.00	8.57	50	
	55						6.14	6.61	7.08	55	
	60						5.16	5.56	5.95	60	
Class 4	65						4.40	4.73	5.07	65	Class 5
	70						3.79	4.08	4.37	70	
	75						3.30	3.56	3.81	75	
	80						2.90	3.13	3.35	80	
Class 5	85	*0.00*	*1.78*	*1.98*	*2.18*	*2.37*	2.57	2.77	2.97	85	Class 6
	90	*0.00*	*1.59*	*1.76*	*1.94*	*2.12*	2.29	2.47	2.65	90	
Class 6	95	0.00	1.42	1.58	1.74	1.90	2.06	2.22	2.37	95	
	100	0.00	1.29	1.43	1.57	1.71	1.86	2.00	2.14	100	
	105	0.00	1.17	1.30	1.43	1.55	1.68	1.81	1.94	105	
	110	0.00	1.06	1.18	1.30	1.42	1.53	1.65	1.77	110	
Class 7	115	0.00	0.97	1.08	1.19	1.30	1.40	1.51	1.62	115	Class 7
	120	0.00	0.89	0.99	1.09	1.19	1.29	1.39	1.49	120	
	125	0.00	0.82	0.91	1.01	1.10	1.19	1.28	1.37	125	
Class 8	130	0.00	0.76	0.85	0.93	1.01	1.10	1.18	1.27	130	Class 8
	135	0.00	0.71	0.78	0.86	0.94	1.02	1.10	1.18	135	
	140	0.00	0.66	0.73	0.80	0.87	0.95	1.02	1.09	140	
	145	0.00	0.61	0.68	0.75	0.82	0.88	0.95	1.02	145	
	150	0.00	0.57	0.63	0.70	0.76	0.83	0.89	0.95	150	
	155	0.00	0.54	0.59	0.65	0.71	0.77	0.83	0.89	155	
	160	0.00	0.50	0.56	0.61	0.67	0.73	0.78	0.84	160	
Class 9	165	0.00	0.47	0.52	0.58	0.63	0.68	0.73	0.79	165	Class 9
	170	0.00	0.44	0.49	0.54	0.59	0.64	0.69	0.74	170	
	175	0.00	0.42	0.47	0.51	0.56	0.61	0.65	0.70	175	
	180	0.00	0.40	0.44	0.49	0.53	0.57	0.62	0.66	180	
	185	0.00	0.38	0.42	0.46	0.50	0.54	0.58	0.63	185	
	190	0.00	0.36	0.40	0.44	0.47	0.51	0.55	0.59	190	
	195	0.00	0.34	0.38	0.41	0.45	0.49	0.53	0.56	195	
	200	0.00	0.32	0.36	0.39	0.43	0.46	0.50	0.54	200	
	205	0.00	0.31	0.34	0.37	0.41	0.44	0.48	0.51	205	
	210	0.00	0.29	0.32	0.36	0.39	0.42	0.45	0.49	210	
	215	0.00	0.28	0.31	0.34	0.37	0.40	0.43	0.46	215	
	220	0.00	0.27	0.30	0.32	0.35	0.38	0.41	0.44	220	

Table 9. Amplitudes for MCAT Simulations Tangent Track Classes 6 through 9

Table 4 of Appendix D to Part 213

Track Class 6 through 9 Amplitude Parameters (in inches)

for MCAT Simulations on Tangent Track

	Gage 56.5"			
	Class 6	Class 7	Class 8	Class 9
Max. Operating Speed (m.p.h.)	110	125	160	220
Max. Simulation Speed (m.p.h.)	115	130	165	225

MCAT Segments	Parameter	Segment Description
Hunting	a_1	(b)(1)(i)
Gage Narrowing	a_2	(b)(1)(ii)
Gage Widening	a_3	(b)(1)(iii)
Repeated Surface	a_9	(b)(1)(iv)
Repeated Alinement	a_4	(b)(1)(v)
Single Surface	a_{10}, a_{11}	(b)(1)(vi)
Single Alinement	a_5, a_6	(b)(1)(vii)
Short Warp	a_{12}	
Combined Perturbation	a_7, a_8, a_{13}	(b)(1)(ix)

		Amplitude Parameters (inches)			
Wavelength λ = 10ft	a_1	0.250	0.250	0.250	0.250
Wavelength λ = 20ft	a_{12}				
Wavelength λ = 31ft	a_2	0.500	0.500	0.500	0.250
	a_3	0.750	0.500	0.500	0.500
	a_4	0.375	0.375	0.375	0.375
	a_5	0.500	0.500	0.500	0.500
	a_6	0.000	0.000	0.000	0.000
	a_7				0.333
	a_8				0.000
	a_9	0.750	0.750	0.500	0.375
	a_{10}	1.000	1.000	0.750	0.500
	a_{11}	0.000	0.000	0.000	0.000
	a_{13}				0.333
Wavelength λ = 62ft	a_2	0.500	0.500	0.500	0.250
	a_3	0.750	0.500	0.500	0.500
	a_4	0.500	0.375	0.375	0.375
	a_5	0.750	0.750	0.750	0.500
	a_6	0.000	0.250	0.250	0.000
	a_7				0.333
	a_8				0.000
	a_9	0.750	0.750	0.750	0.500
	a_{10}	1.000	1.000	1.000	0.750
	a_{11}	0.000	0.000	0.000	0.000
	a_{13}				0.500
Wavelength λ = 124ft	a_2	0.500	0.500	0.500	0.250
	a_3	0.750	0.750	0.750	0.750
	a_4	1.000	0.875	0.500	0.500
	a_5	1.500	1.250	1.000	0.750
	a_6	0.750	0.500	0.250	0.000
	a_7				0.500
	a_8				0.000
	a_9	1.250	1.000	0.875	0.625
	a_{10}	1.750	1.500	1.250	1.000
	a_{11}	0.250	0.000	0.000	0.000
	a_{13}				0.667

Table 10. Amplitudes for MCAT Simulations: Curved Track Classes 6 through 9

Table 5 of Appendix D to Part 213

Track Classes 6 through 9 Amplitude Parameters (in inches)
for MCAT Simulations on Curved Track with Cant Deficiency > 3 and ≤ 5 Inches

		Gage 56.5"				Gage 57.0"			
		Class 6	Class 7	Class 8	Class 9	Class 6	Class 7	Class 8	Class 9
Max. Operating Speed (m.p.h.)		110	125	160	220	110	125	160	220
Max. Simulation Speed (m.p.h.)		115	130	165	225	115	130	165	225
MCAT Segments	**Parameter**	**Segment Description**				**Segment Description**			
Hunting	a_1	(b)(1)(i) [1]				(b)(1)(i) [1]			
Gage Narrowing	a_2	(b)(1)(ii)				(b)(1)(ii)			
Gage Widening	a_3	(b)(1)(iii)				(b)(1)(iii)			
Repeated Surface	a_9	(b)(1)(iv)				(b)(1)(iv)			
Repeated Alinement	a_4	(b)(1)(v)				(b)(1)(v)			
Single Surface	a_{10}, a_{11}	(b)(1)(vi)				(b)(1)(vi)			
Single Alinement	a_5, a_6	(b)(1)(vii)				(b)(1)(vii)			
Short Warp	a_{12}	(b)(1)(viii)				(b)(1)(viii)			
Combined Perturbation	a_7, a_8, a_{13}				(b)(1)(ix)				(b)(1)(ix)
		Amplitude Parameters (inches)				**Amplitude Parameters (inches)**			
Wavelength λ = 10ft	a_1	0.250[1]	0.250[1]	0.250[1]	0.250[1]	0.250[1]	0.250[1]	0.250[1]	0.250[1]
Wavelength λ = 20ft	a_{12}	0.625	0.563	0.500	0.375	0.625	0.563	0.500	0.375
Wavelength λ = 31ft	a_2	0.500	0.500	0.500	0.250	0.500	0.500	0.500	0.500
	a_3	0.750	0.500	0.500	0.500	0.250	0.250	0.250	0.500
	a_4	0.375	0.375	0.375	0.375	0.375	0.375	0.375	0.375
	a_5	0.500	0.500	0.500	0.500	0.500	0.500	0.500	0.500
	a_6	0.000	0.000	0.000	0.000	0.250	0.250	0.250	0.250
	a_7				0.333				0.333
	a_8				0.000				0.083
	a_9	0.750	0.750	0.500	0.375	0.750	0.750	0.500	0.375
	a_{10}	1.000	1.000	0.750	0.500	1.000	1.000	0.750	0.500
	a_{11}	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	a_{13}				0.333				0.333
Wavelength λ = 62ft	a_2	0.500	0.500	0.500	0.250	0.500	0.500	0.500	0.500
	a_3	0.750	0.500	0.500	0.500	0.250	0.250	0.250	0.250
	a_4	0.500	0.375	0.375	0.375	0.500	0.375	0.375	0.375
	a_5	0.625	0.500	0.500	0.500	0.625	0.500	0.500	0.500
	a_6	0.000	0.000	0.000	0.000	0.375	0.250	0.250	0.250
	a_7				0.333				0.333
	a_8				0.000				0.083
	a_9	0.750	0.750	0.750	0.500	0.750	0.750	0.750	0.500
	a_{10}	1.000	1.000	1.000	0.750	1.000	1.000	1.000	0.750
	a_{11}	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	a_{13}				0.500				0.500
Wavelength λ = 124ft	a_2	0.500	0.500	0.500	0.250	1.000	1.000	1.000	0.750
	a_3	0.750	0.750	0.750	0.750	0.250	0.250	0.250	0.250
	a_4	1.000	0.875	0.500	0.500	1.000	0.875	0.500	0.500
	a_5	1.500	1.250	0.750	0.750	1.500	1.250	0.750	0.750
	a_6	0.750	0.500	0.000	0.000	1.250	1.000	0.500	0.500
	a_7				0.500				0.500
	a_8				0.000				0.250
	a_9	1.250	1.000	0.875	0.625	1.250	1.000	0.875	0.625
	a_{10}	1.750	1.500	1.250	1.000	1.750	1.500	1.250	1.000
	a_{11}	0.250	0.000	0.000	0.000	0.250	0.000	0.000	0.000
	a_{13}				0.667				0.667

[1] For curves <1 degree

3.11 Low-Speed Wheel Climb Derailment

The low-speed derailment simulations were conducted based on 78 FR 16358–Safety Advisory 2013-02 [66]. They are a vital consideration when using high-speed passenger cars in shared operation with freight cars. The purpose of the simulations was to test the ability of the suspension to navigate severe track warp conditions at low speeds. Due to the stiff primary suspension of some passenger trucks, wheel-climb derailments are a concern for these types of track environments.

Theoretical track warp cases were constructed in NUCARS® as per the recommendations in 78 FR 16358. All cases were run through a 12-degree curve with a coefficient of friction of 0.5 representing dry rail conditions. The track warp condition was simulated as a negative vertical perturbation on the outside rail at the center of the curve. The perturbation was sinusoidal in shape with varied wavelengths of 10, 20, 40, and 62 feet as well as varied amplitude of 0.5 inch to 3.0 inches in 0.5-inch increments. Figure 23 shows from top to bottom the NUCARS® track geometry input for left rail lateral and vertical, right rail lateral and vertical, curvature, and superelevation.

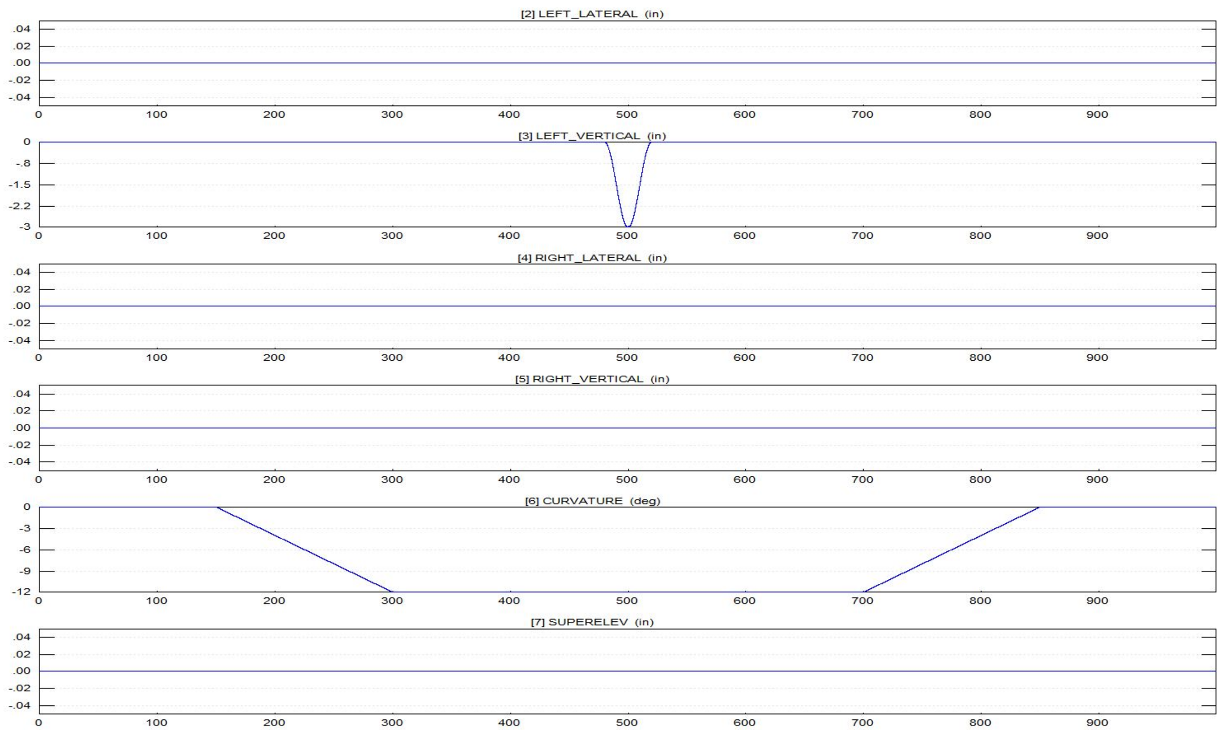

Figure 23. Low-Speed Derailment Example Track Geometry

3.12 Static Lean Simulations

Static lean simulations were performed based on the standards in 49 CFR § 213.329 to determine wheel unloading for specified cant deficiencies [67]. To reach the maximum value of 7 inches, the superelevation was gradually increased in increments of 1 inch. Table 11 shows a summary of the criteria listed in 49 CFR § 213.329.

Table 11. 49 CFR § 213.329 Static Lean Test Criteria

Test Criteria	Value
Maximum superelevation	7 inches
Minimum wheel load of any wheel	60% of the static value
Maximum roll angle between floor of the vehicle and horizontal	8.6 degrees

3.13 Static Wheel Load Equalization

Truck load equalization simulations were conducted to test the ability of the suspension to equalize vertical wheel loads. These simulations are based on the wheel load equalization tests recommended by the APTA in specification PRM-S-014-06 [68]. Tests were performed using a theoretical NUCARS® input in which each individual wheel was incrementally lifted and dropped by 1, 2, 2.5, and 3 inches.

APTA states two sets of requirements in M-S-014-06. The AAR requirement for freight car trucks is in AAR MSRP Specification M-976 [69]. It is recommended that trucks should meet the APTA Class R requirements before beginning track tests.

The APTA Class G requirement is meant for operations where the track twist (i.e., difference in crosslevel between two points in the track) is maintained to less than 3 inches over 62 feet of track length. It requires that a vehicle maintains 35 percent of its nominal wheel load when a wheel is raised or dropped 2.5 inches, and additionally, it should not have a wheel lift when a wheel is raised or dropped 3 inches.

The APTA Class R requirement is meant for operations where the track twist is maintained to less than 3 inches over 62 feet track length and additionally is limited to no more than 2.25 inches over 10 feet. It requires that a vehicle maintains 35 percent of its nominal wheel load when a wheel is raised or dropped 2 inches, and additionally, it should not have a wheel lift when a wheel is raised or dropped 2.5 inches.

The AAR's truck Specification M-976 requires that with an empty car on level track, vertical wheel loads are to be measured while raising and lowering one wheel from 0 to 3 inches in 0.5-inch increments. AAR Specification M-976 states that vertical load may not drop below 40 percent of the nominal static load and that the side bearing maximum travel may not be exceeded. Side bearing travel (required by M-976) was not evaluated for these simulations, because it is primarily applicable to side bearings designed for freight service.

Table 12 shows a summary of the test criteria listed in APTA M-S-014-06 and AAR M-976.

Table 12. Wheel Load Equalization Test Criteria

Test Criteria	Condition	Minimum Allowable Wheel Load
APTA Class R	Wheel raised or dropped 2 inches Wheel raised or dropped 2.5 inches	35% >0
APTA Class G	Wheel raised or dropped 2.5 inches Wheel raised or dropped 3 inches	35% >0
AAR M-976	Wheel raised and dropped 3 inches Additionally, side bearing travel may not be exceeded.	40%

3.14 Numerical Modeling Vehicle Performance Results

Numerical modeling results are presented separately in this section for each of the simulation regimes evaluated. Sample results will be presented and full results will be presented in separate appendices. All results shown are intended to emphasize the comparative analysis of one design to the next and less on the actual values of the predicted simulation results as these mathematical models are stripped down "generic" representations of the various truck designs.

3.14.1 AAR Chapter 11

Although AAR Chapter 11 is not a requirement for passenger equipment, it is frequently used by TTCI and other agencies to evaluate the performance of passenger equipment. Evaluations over AAR Chapter 11 regimes are helpful in determining vehicle resonant speeds, curving performance, general dynamic behavior and safety. Because the test zones contain perturbations of defined amplitude and wavelength, tests conducted over these zones are very effective for validating computer simulation models. The Chapter 11 regimes evaluated are detailed in Section 3.7. The evaluation criteria for the Chapter 11 regimes are shown in Table 6.

Constant Curving

Constant curving and standard spiral negotiation simulations were conducted to evaluate each truck's curve negotiation capability. Constant curving and standard spiral negotiation simulations used measured track geometry from the 7.5-, 10-, and 12-degree curves of the WRM loop at the TTC. Simulation speeds correspond to 3-inch underbalance, balance, and 3-inch overbalance operation through the curves (12, 24, and 32 mph [19, 38, 52 km/h]). Simulations were also conducted in both the clockwise and counterclockwise operating directions. Nine different curve segments were simulated for the curving analyses. Table 13 summarizes the curves used in the simulations and provides the designations that are used throughout the analysis.

Table 13. Summary of Curves and Spirals Used for Curving Analyses

Designation	Description
75 SS	7.5-degree south spiral
75 NS	7.5-degree north spiral
75 CRV	7.5-degree curve
10 SS	10-degree south spiral
10 NS	10-degree north spiral
10 CRV	10-degree curve
12 BS	12-degree south spiral
12 SS	12-degree bunched spiral
12 CRV	12-degree curve

Output was compared to AAR Chapter 11 limits as listed in Table 6. In addition to the AAR Chapter 11 criteria, the maximum axle angle-of-attack is also shown for each results entry for relative curving comparisons.

Table 14 shows the results for all truck types and each car type for the 7.5-degree south spiral running in the clockwise direction. None of the evaluation criteria were exceeded. Curving results for all other curves and spirals are included in Appendix F.

Table 14. Chapter 11 Curving Results for 7.5–Degree South Spiral, Clockwise Direction

Speed (mph)	Max Roll Angle (deg)	50 ms/3ft Max wheel L/V	6 ft Max truck side L/V	3 ft/50 ms Min vertical wheel load	50 ms/ 3 ft Max axle sum L/V	Max 95% Wheel L/V	Max 95% axle sum L/V	Max Angle of Attack (mrad)
Criterion								
	< 6	< 1.0	< 0.6	> 10%	< 1.5	< 0.8	< 1.5	N/A
Equalizer Beam, SL								
12	0.5	0.66	0.31	68.4%	1.13	0.57	1.05	12.58
24	0.5	0.63	0.30	65.0%	1.08	0.57	1.05	12.06
32	1.0	0.60	0.28	62.2%	1.08	0.59	1.06	11.75
Equalizer Beam, BL								
12	0.8	0.64	0.29	70.5%	1.13	0.59	1.08	12.47
24	1.5	0.57	0.27	74.1%	1.05	0.55	1.03	12.09
32	1.4	0.56	0.28	61.3%	1.01	0.54	1.01	11.72
Radial Arm, SL								
12	0.5	0.66	0.30	67.7%	1.16	0.58	1.06	12.31
24	0.5	0.63	0.28	64.0%	1.11	0.59	1.06	11.71
32	1.1	0.62	0.26	58.6%	1.10	0.60	1.07	11.26
Radial Arm, BL								
12	1.8	0.79	0.31	59.0%	1.28	0.65	1.13	12.25
24	1.6	0.68	0.30	65.4%	1.17	0.59	1.07	11.61
32	1.1	0.58	0.25	63.1%	1.05	0.54	1.01	10.97
Rubber Chevron, SL								
12	0.5	0.60	0.29	64.2%	1.08	0.56	1.03	10.26
24	0.8	0.68	0.27	54.0%	1.16	0.55	1.02	9.80
32	1.5	0.59	0.29	61.6%	1.07	0.56	1.01	9.55
Rubber Chevron, BL								
12	1.7	0.77	0.29	60.0%	1.25	0.62	1.08	9.28
24	1.8	0.65	0.27	62.5%	1.12	0.53	0.97	8.92
32	1.2	0.51	0.25	61.7%	0.96	0.48	0.92	8.72
Conical Spring, SL								
12	0.6	0.58	0.28	64.7%	1.07	0.51	0.98	8.74
24	0.7	0.56	0.26	62.5%	1.03	0.51	0.97	8.39
32	1.6	0.54	0.27	54.3%	1.01	0.49	0.95	8.31
Conical Spring, BL								
12	1.5	0.67	0.26	60.2%	1.16	0.50	0.97	7.44
24	2.0	0.56	0.25	65.9%	1.03	0.46	0.91	7.25
32	1.6	0.46	0.25	65.9%	0.91	0.45	0.85	7.14
Journal Spring, SL								
12	0.6	0.66	0.30	72.2%	1.15	0.58	1.06	11.36
24	0.8	0.64	0.27	68.5%	1.12	0.58	1.06	10.94
32	1.6	0.56	0.26	66.9%	1.05	0.59	1.05	10.57
Journal Spring, BL								
12	0.8	0.71	0.29	73.3%	1.20	0.63	1.11	11.40
24	1.6	0.65	0.29	69.5%	1.12	0.59	1.06	11.01
32	0.7	0.55	0.25	71.0%	1.03	0.53	1.00	10.57

Dynamic Curve

Figure 24 shows the result of the dynamic curve simulations for the single-level car in the clockwise direction. The rubber chevron trucks show exceedance of the wheel lateral-to-vertical (L/V) ratio and axle sum L/V ratio at 24 mph (38 km/h). No exceptions were shown for the maximum carbody roll or minimum vertical wheel load criterion, although the rubber chevron does show poorer performance than the other trucks.

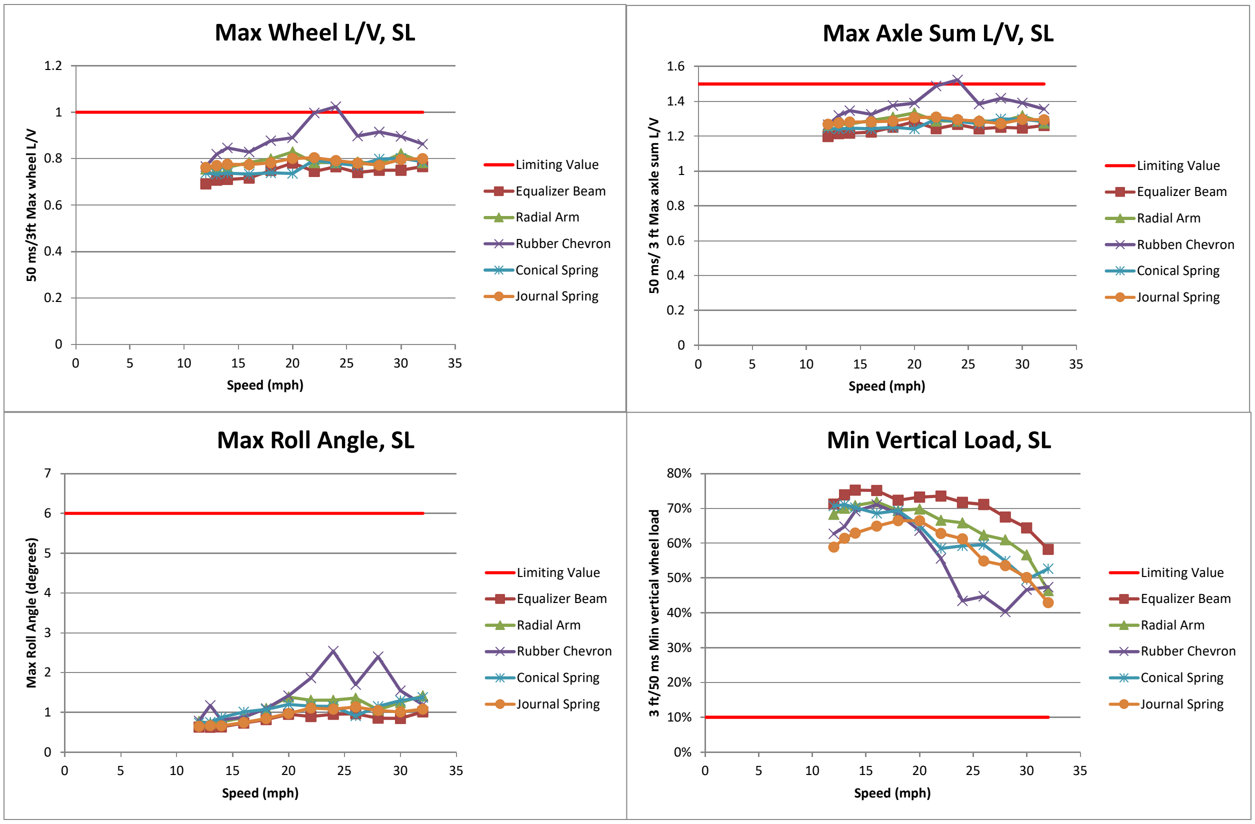

Figure 24. Dynamic Curve Results, Single-Level Car, Clockwise Direction

Figure 25 shows the results of the dynamic curve simulations for the bi-level car in the clockwise direction. There are no exceedances of the AAR Chapter 11 criteria; however, the rubber chevron and radial arm trucks are very near the wheel L/V ratio and axle sum L/V ratio limits.

Figure 25. Dynamic Curve Results, Bi-Level Car, Clockwise Direction

Figure 26 shows the results of the dynamic curve simulations for the single-level car in the counterclockwise direction. The rubber chevron truck shows exceedance of the wheel L/V ratio and axle sum L/V ratio at 32 mph (52 km/h). The rubber chevron shows poorer performance than the other trucks for all other criteria.

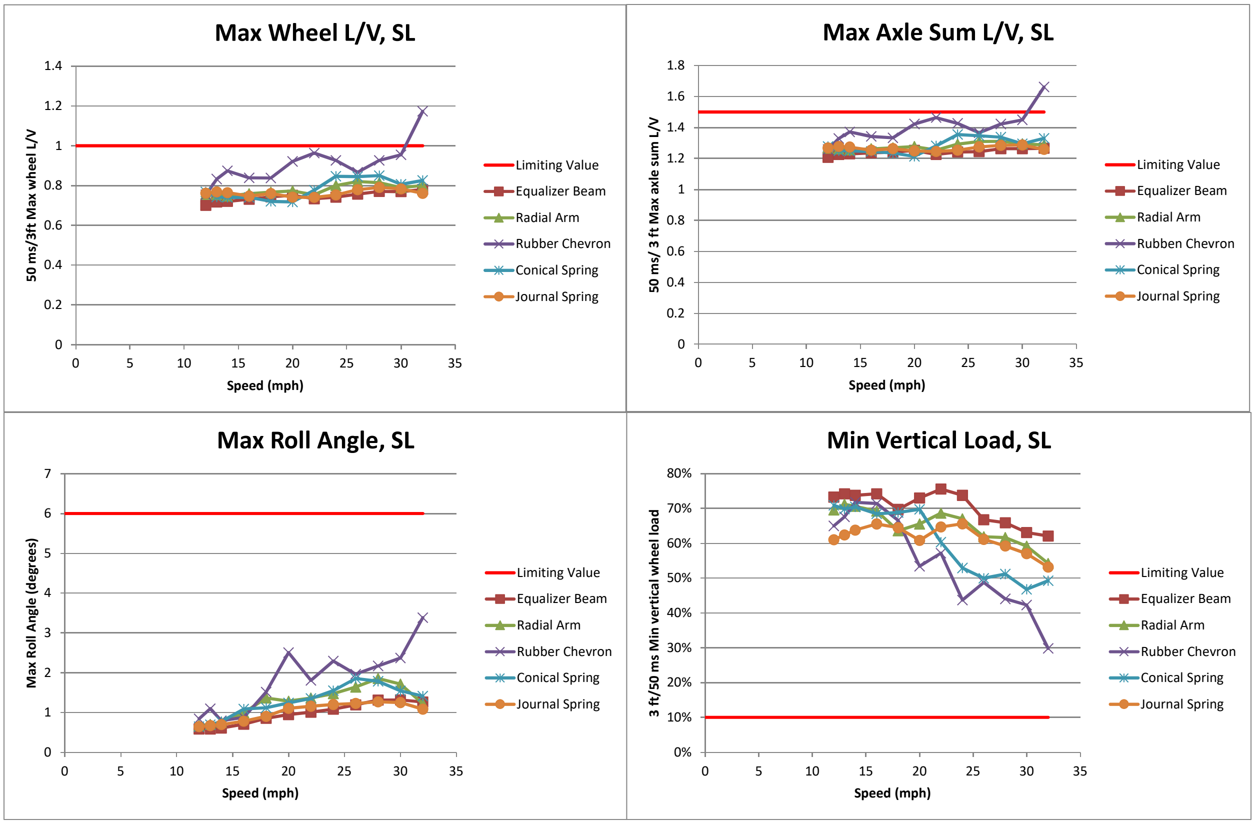

Figure 26. Dynamic Curve Results, Single-Level Car, Counterclockwise Direction

Figure 27 shows the results of the dynamic curve simulations for the bi-level car in the counterclockwise direction. There are no exceedances of the AAR Chapter 11 criteria. However, the radial arm, rubber chevron, and conical spring trucks are very near the limit of maximum wheel L/V ratio and axle sum L/V ratio at 18 mph (29 km/h).

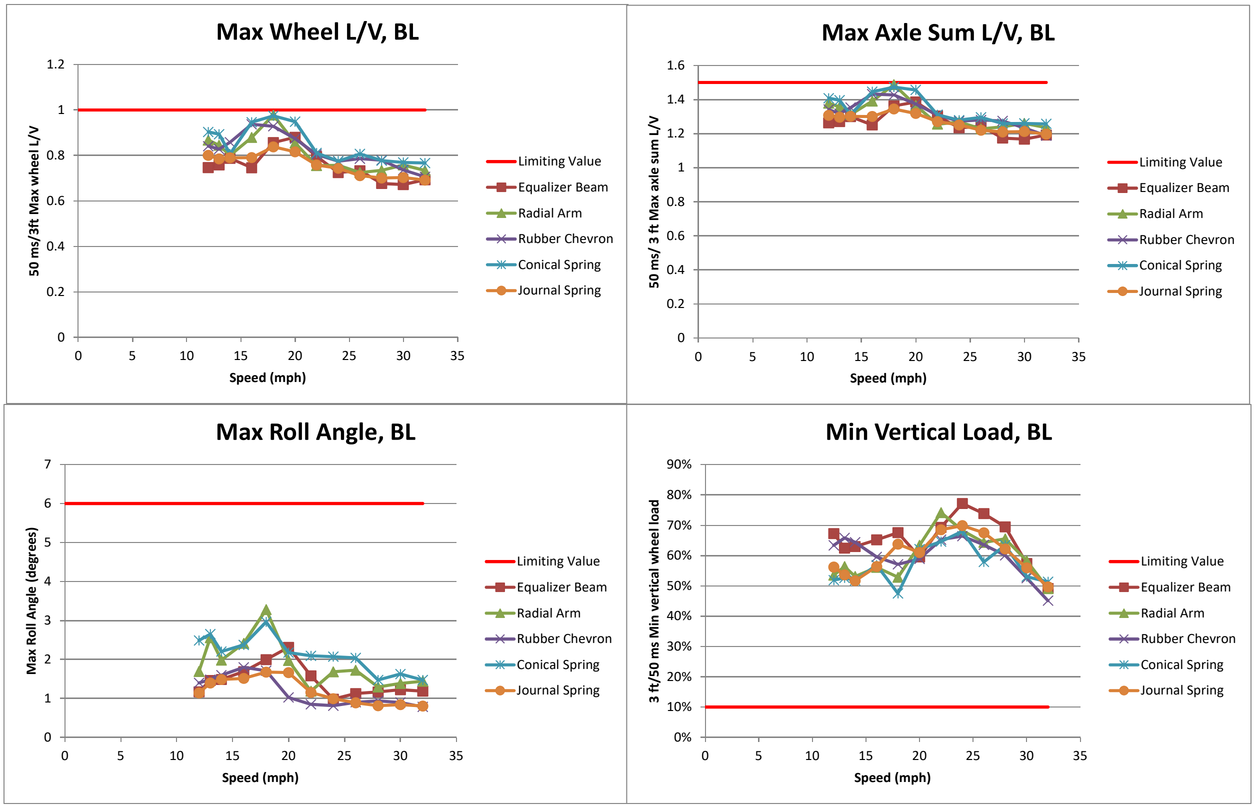

Figure 27. Dynamic Curve Results, Bi-Level Car, Counterclockwise Direction

Limiting Spiral

Figure 28 shows the results for the limiting spiral entry simulations for the single-level car in the clockwise direction. Performance in the limiting spiral is usually an indication of wheel load equalization. The upper two plots of the figure show no exceedances of single wheel L/V ratio nor axle sum L/V ratio, but the lower plot of Figure 28 does show a clear distinction of predicted minimum vertical wheel load of each truck design. The results show the equalizer beam truck to the highest comparative minimum vertical wheel load while the journal spring design shows the lowest. All trucks design shows a decreasing trend with increasing speed, with the conical spring design showing a dramatic decrease above 28 mph (45 km/h).

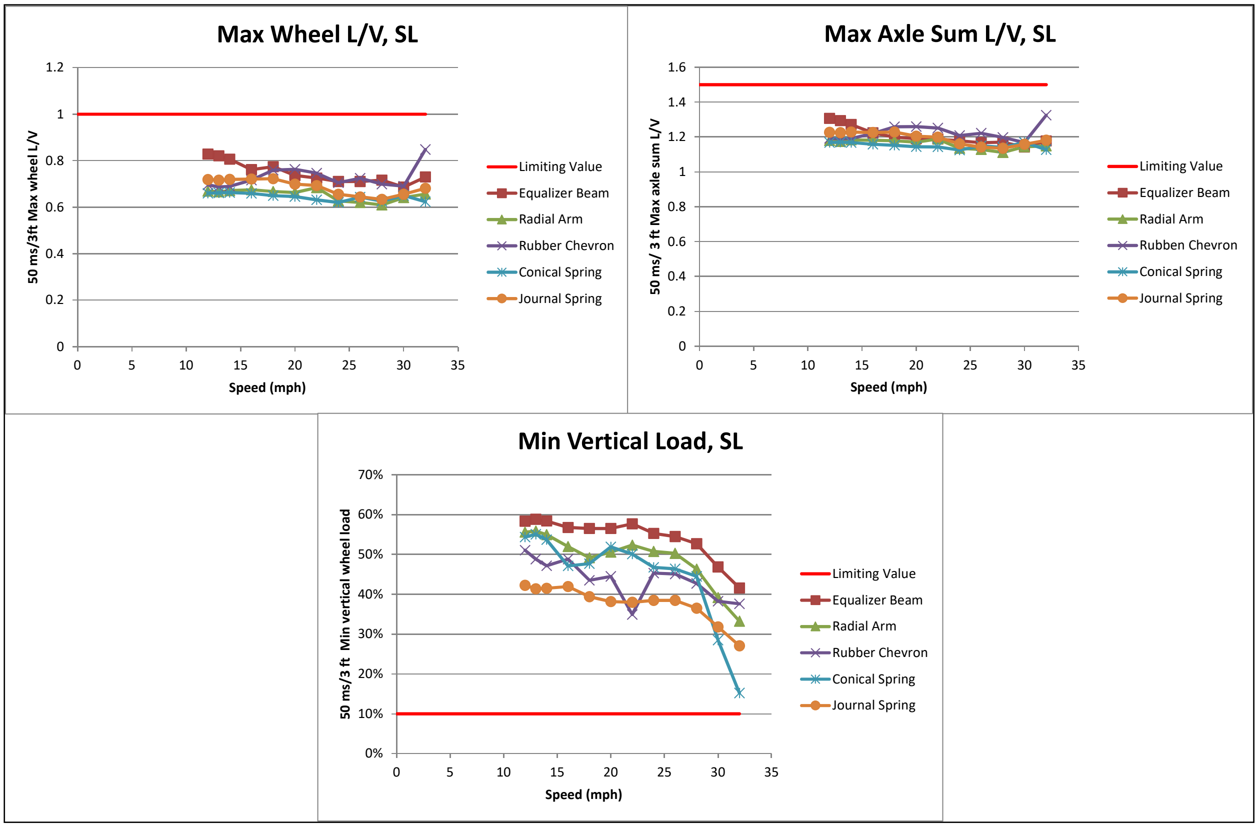

Figure 28. Limiting Spiral Entry Results, Single-Level Car, Clockwise Direction

Figure 29 shows the results for the limiting spiral simulations for the bi-level car in the clockwise direction. The upper two plots of the figure show no exceedances of single wheel L/V ratio nor axle sum L/V ratio. The minimum vertical wheel loads shown in the lower plot show minimum values around 40 percent of static wheel load at 22 and 24 mph (35 and 38 km/h).

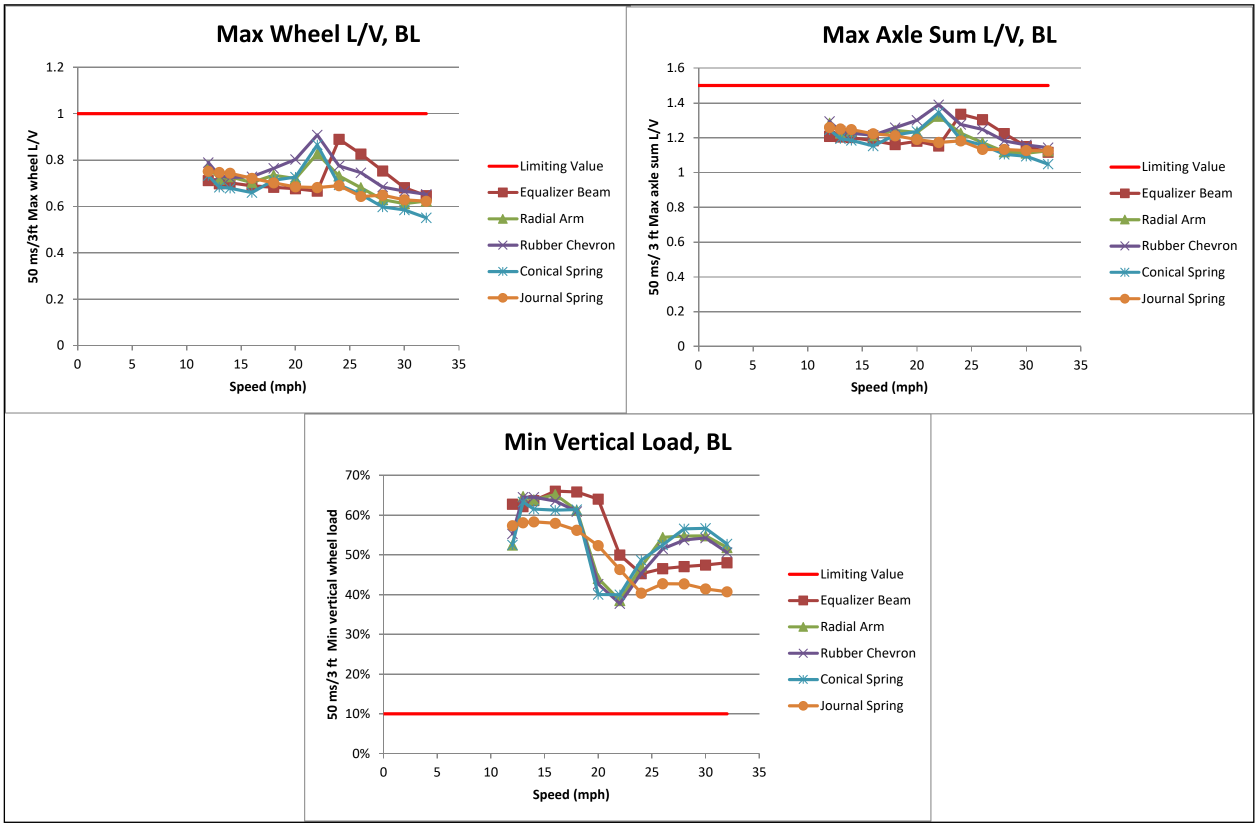

Figure 29. Limiting Spiral Results, Bi-Level Car, Clockwise Direction

Figure 30 shows the results for the limiting spiral exit simulations for the single-level car in the counterclockwise direction. The journal spring truck exceeds the limits of both the single wheel L/V ratio and axle sum L/V ratio at speeds below 20 mph (32 km/h). The journal spring also shows the least favorable results of minimum vertical wheel load at the lower speeds but improve at speeds above 20 mph (32 km/h).

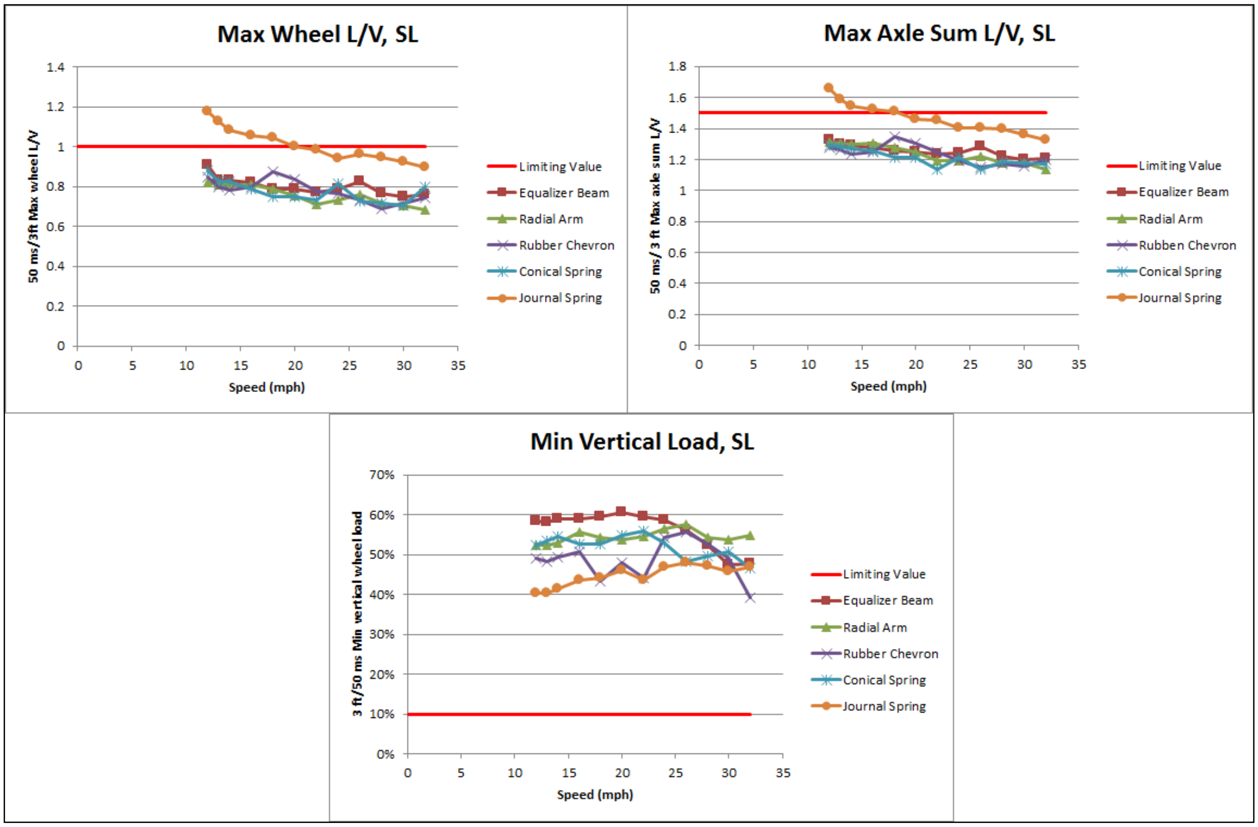

Figure 30. Limiting Spiral Exit Results, Single-Level Car, Counterclockwise Direction

Figure 31 shows the results for the limiting spiral exit simulations for the bi-level car in the counterclockwise direction. Results for single wheel and axle sum L/V ratio are all below the limiting criteria. The minimum vertical wheel load results are all above the limiting criterion of 10 percent, with the equalizer beam truck showing the better result.

Figure 31. Limiting Spiral Exit Results, Bi-Level Car, Counterclockwise Direction

Pitch and Bounce Regime

Figure 32 shows the results of minimum vertical wheel load and dynamic augment vertical acceleration for the pitch and bounce simulation regime. The results show very similar results for both the single-level and bi-level models for the range of speeds simulated. This is not surprising as the models are using the same secondary suspension characteristics. There is a slight difference of the rubber chevron primary suspension, but nowhere near the limiting criterion.

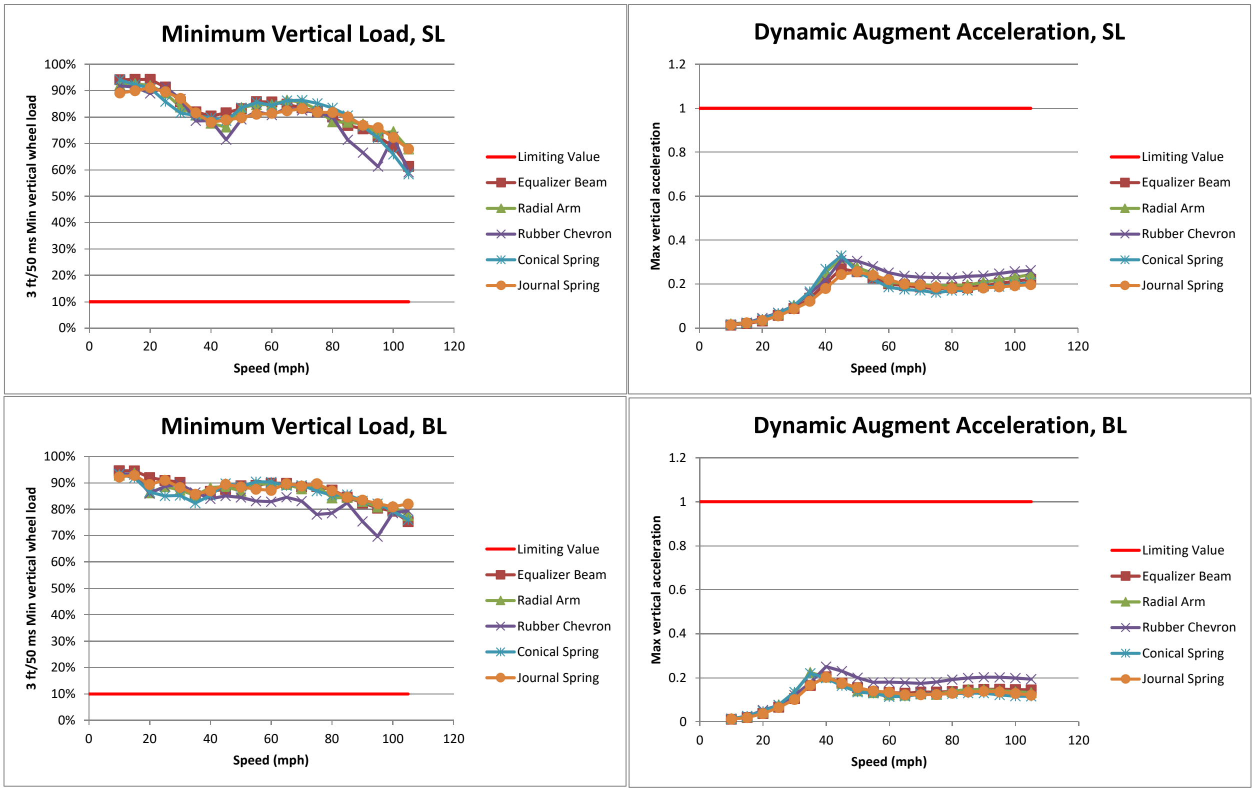

Figure 32. Pitch and Bounce Simulation Results, Minimum Vertical Wheel Load, and Dynamic Augment Acceleration

Twist and Roll Regime

Figure 33 shows the results of minimum vertical wheel load and dynamic augment vertical acceleration for the twist and roll simulation regime. The minimum vertical wheel load results for the single-level car show the equalizer beam and radial arm trucks as having the better results. The minimum vertical wheel load results for the bi-level car also show the equalizer beam and radial arm truck having slightly better results than the other trucks, but all are well above the limiting criteria. The results of vertical dynamic augment acceleration are all well below the limiting criteria.

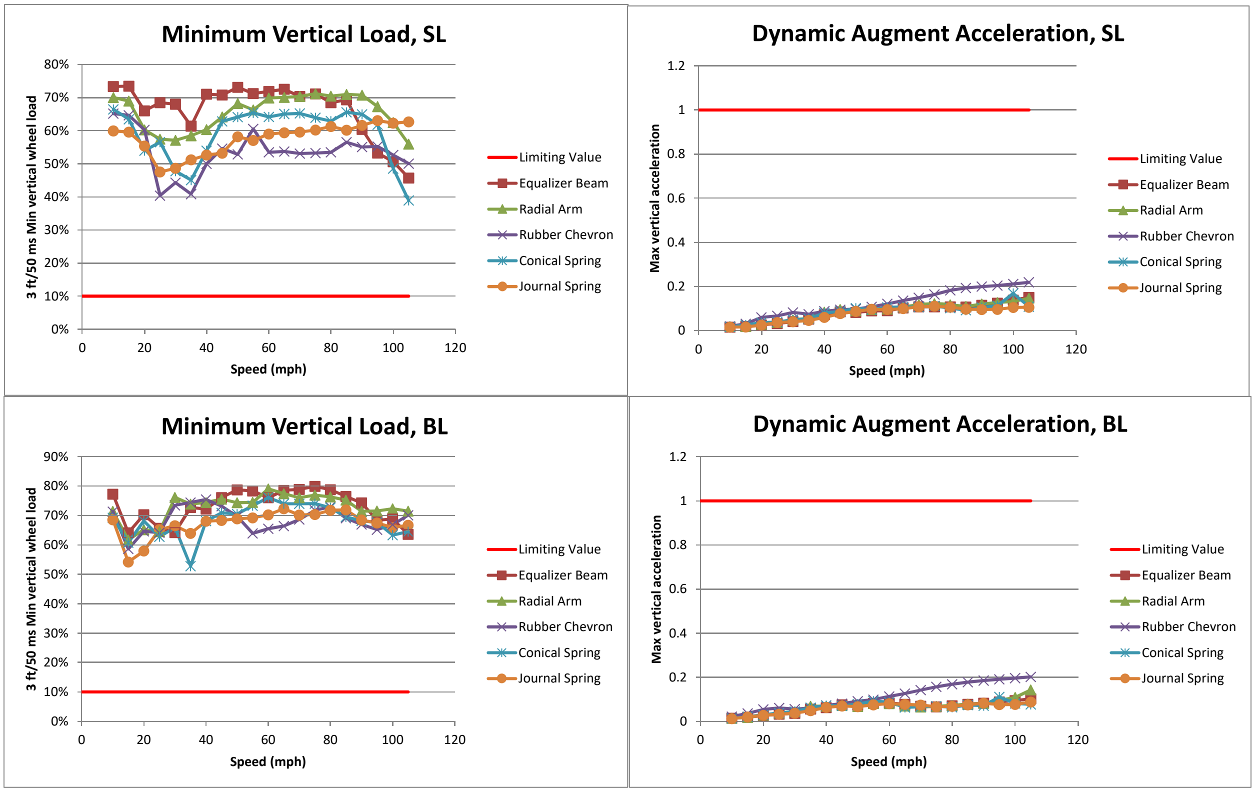

Figure 33. Twist and Roll Simulation Results, Minimum Vertical Wheel Load, and Dynamic Augment Acceleration

Figure 34 shows the results of maximum carbody roll angle and maximum axle sum L/V ratio for the twist and roll simulation regime. It is important to note that AAR Chapter 11 only evaluates twist and roll up 70 mph (113 km/h), whereas these simulations are to 105 mph (169 km/h) to demonstrate higher speed capability. The single-level maximum axle sum L/V ratio values for all trucks trend upward beginning at 70 mph (113 km/h), but do not exceed the limit.

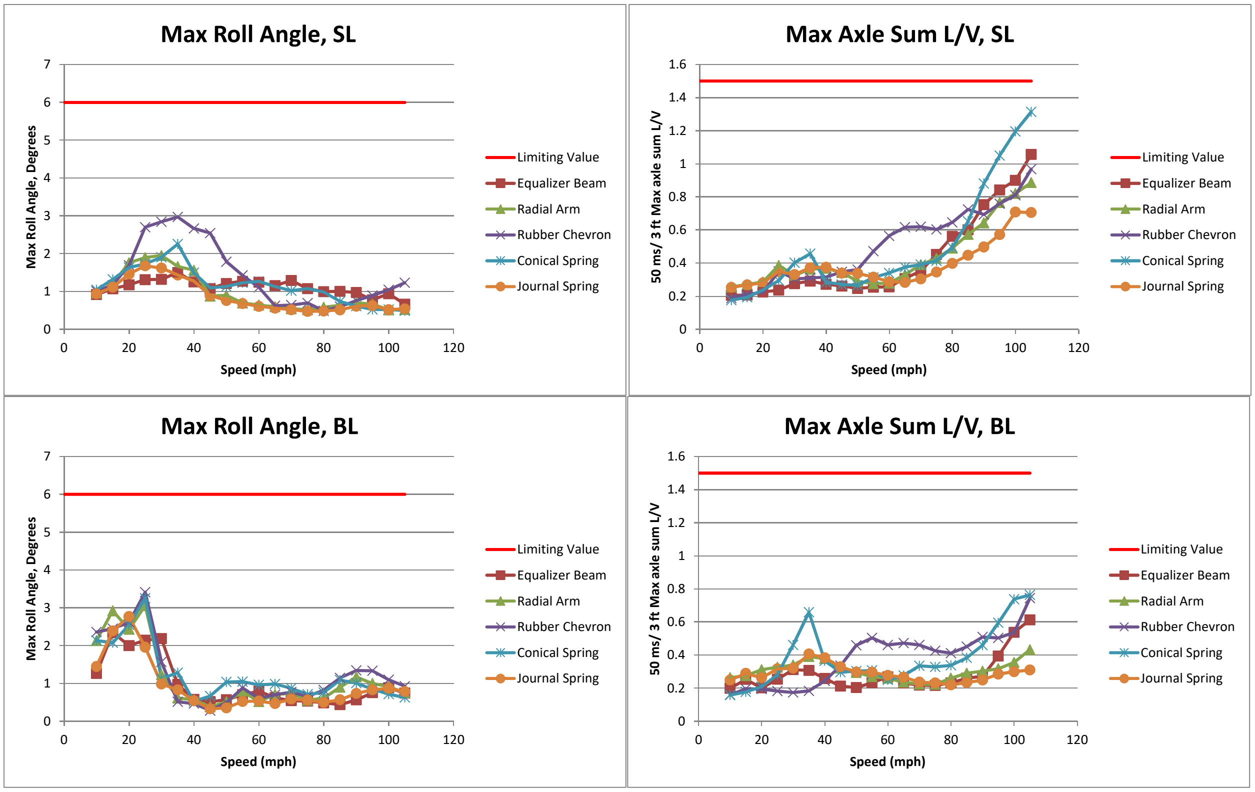

Figure 34. Twist and Roll Simulation Results, Maximum Carbody Roll Angle, and Maximum Axle Sum L/V Ratio

Yaw and Sway Regime

Figure 35 shows the results of maximum truck side L/V ratio and maximum axle sum L/V ratio for both the single-level and bi-level cars over the yaw and sway simulation regime. These results show that the rubber chevron and conical spring suspension perform much worse for maximum truck side L/V ratio than the other truck suspensions. The conical spring exceeds truck side L/V criteria limit at the higher speeds, above 100 mph (161 km/h) under the single-level car and also exceeds the maximum truck side L/V ratio under the bi-level car at 40 mph (64 km/h). The conical spring suspension also exceeds the maximum axle sum L/V ratio limit at speeds above 90 mph (145 km/h). The results for the equalizer beam, radial arm and journal spring are all very similar and do not exceed either the maximum truck side or axle sum L/V limits.

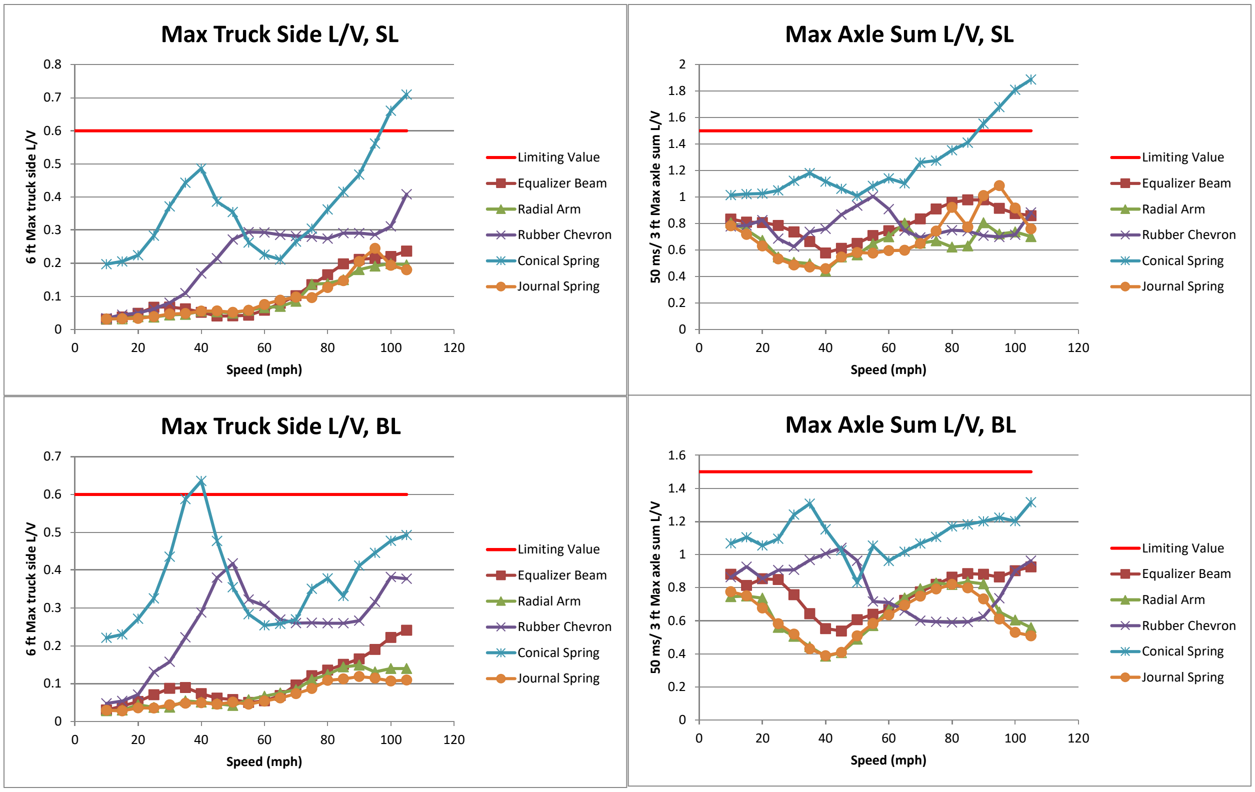

Figure 35. Yaw and Sway Simulation Results, Maximum Truck Side L/V, and Maximum Axle Sum L/V Ratio

High-Speed Stability (Hunting) Regime

The hunting results are shown in Figure 36 through Figure 38. The results are presented for separate sections of the RTT; a tangent section and two curve sections, one representing the north curve of the RTT and the other of the south curve of the RTT. Figure 36 shows the results of maximum carbody lateral acceleration and standard deviation of lateral carbody acceleration on the tangent section of the RTT. The results show all trucks are stable up to 105 mph (169 km/h), where the rubber chevron suspension shows a dramatic instability change for both the single- and bi-level cars. The conical spring suspension shows an upward trend at speeds above 100 mph (161 km/h) and an exceedance of the standard deviation limiting criteria at 125 mph (201 km/h) under the bi-level car.

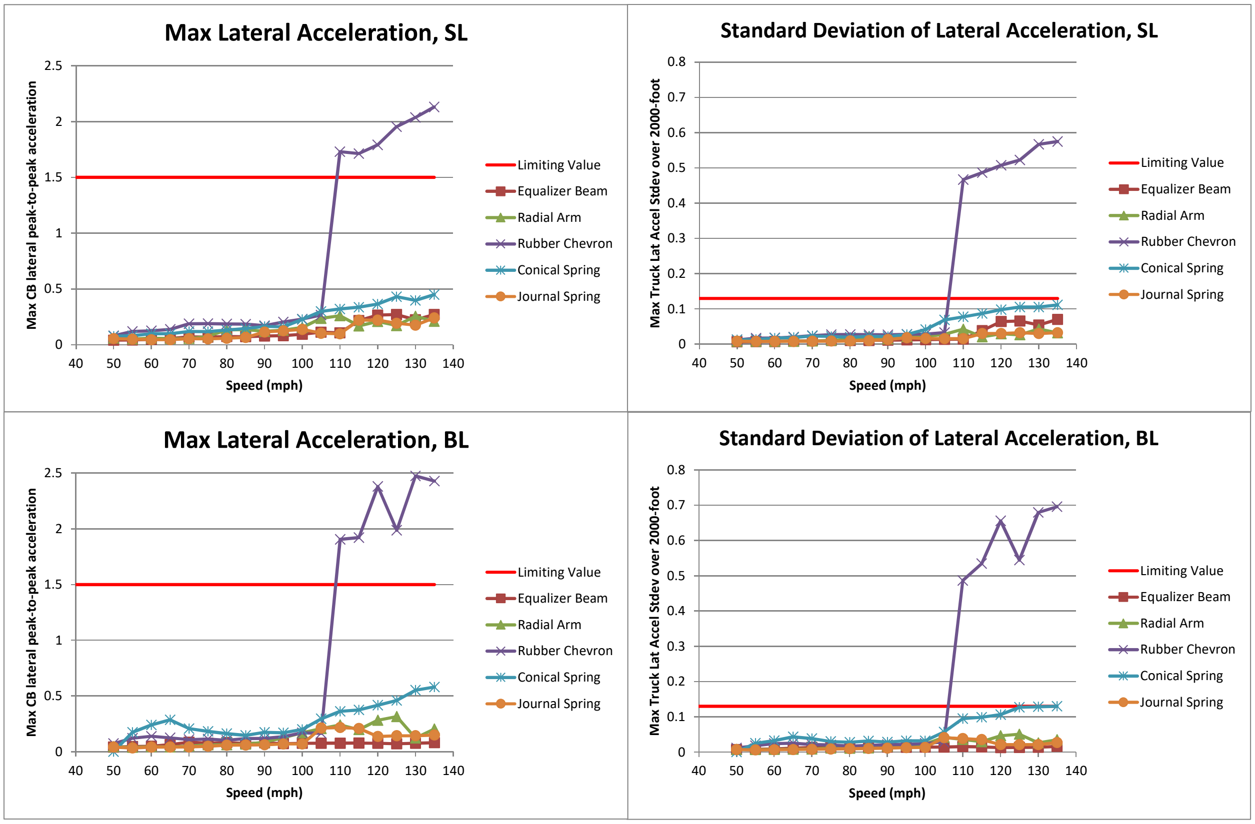

Figure 36. High-Speed Stability (Hunting) Results, RTT Tangent Track

Figure 37 shows the results of maximum carbody lateral acceleration and standard deviation of lateral carbody acceleration on the north curve section of the RTT. The north curve of the RTT is a 0.83-degree curve with 6 inches of superelevation. Balance speed for the curve is 102 mph (164 km/h). Similar to the tangent results, all trucks are stable up to 105 mph (169 km/h), where again the rubber chevron suspension shows a dramatic change in stability, exceeding the performance criteria above 105 mph (169 km/h). The conical spring suspension also shows higher maximum lateral acceleration for both the single- and bi-level cars than that of the tangent track, but still well below the limit but does exceed the standard deviation criteria for both cars at the high end speeds over 130 mph (209 km/h).

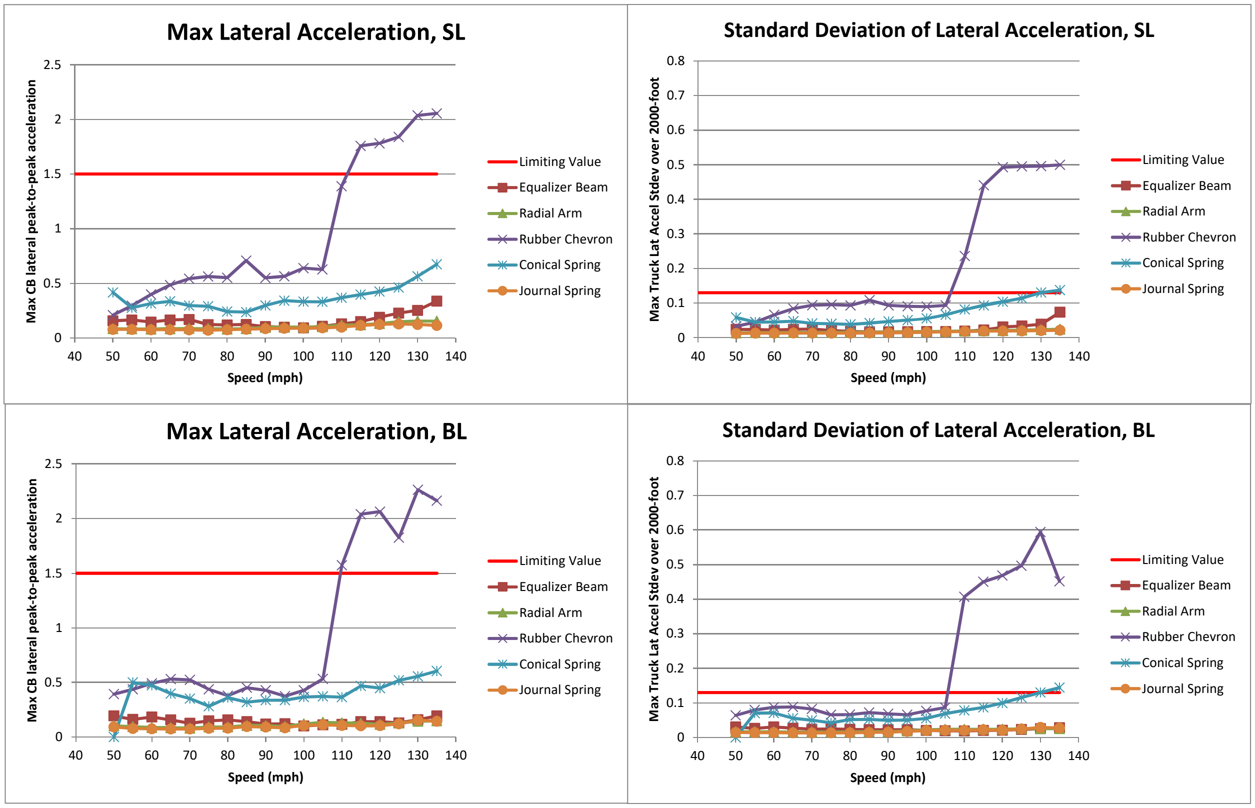

Figure 37. High-Speed Stability (Hunting) Results, RTT North Curve

Figure 38 shows the results of maximum carbody lateral acceleration and standard deviation of lateral carbody acceleration on the south curve section of the RTT. The south curve of the RTT is also a 0.83-degree curve with 6 inches of superelevation. Balance speed for the curve is 102 mph (164 km/h). The results of the south curve are very similar to the north curve results.

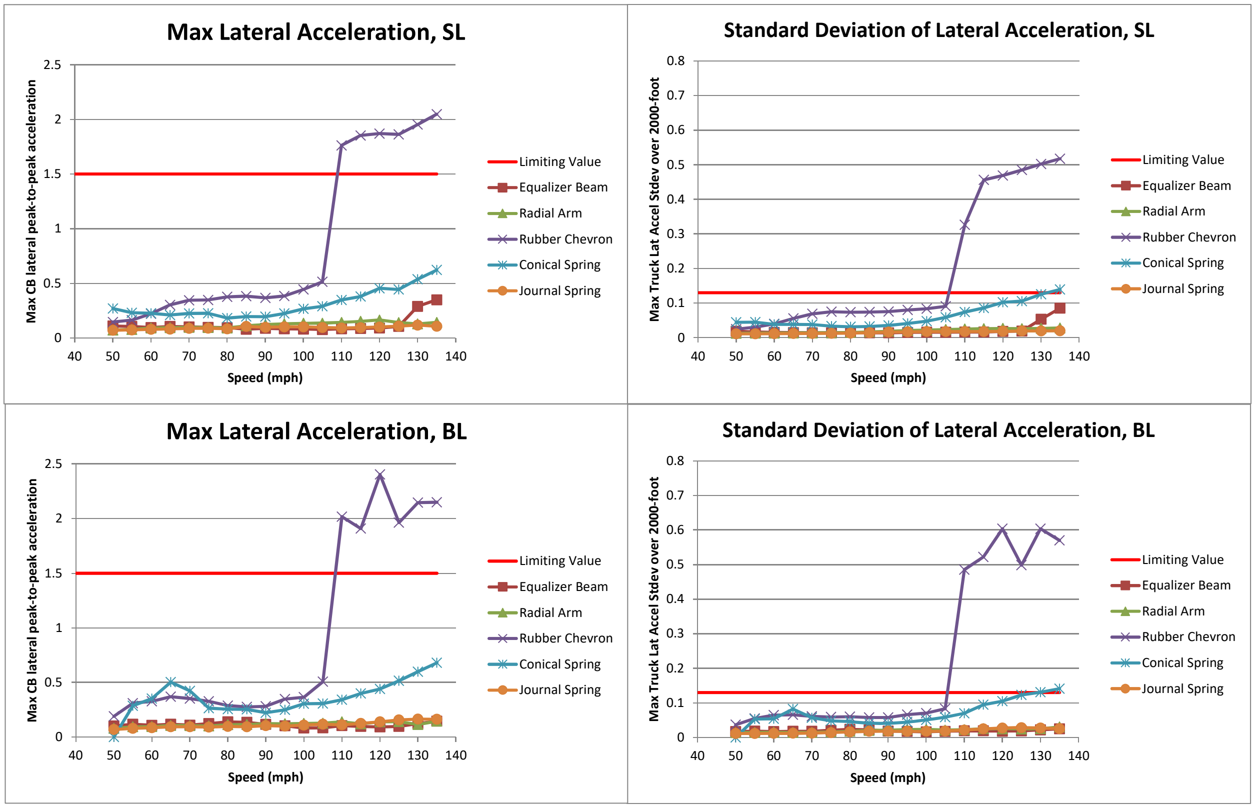

Figure 38. High-Speed Stability (Hunting) Results, RTT South Curve

In an effort to improve the high-speed stability performance of the rubber chevron suspension, parameter variations of the primary suspension longitudinal stiffness were made by increasing the longitudinal stiffness by 50-percent and 100-percent on the single-level car only. Simulations were made of the higher speeds (100+ mph (161+ km/h)) for comparative analysis.

The results for the tangent section, the north curve, and south curve are shown in Figure 39 through Figure 41, respectively. The results show a slight reduction of both maximum lateral acceleration and standard deviation of the lateral acceleration, however, results still exceed the exceeding the performance criteria above 105 mph (169 km/h).

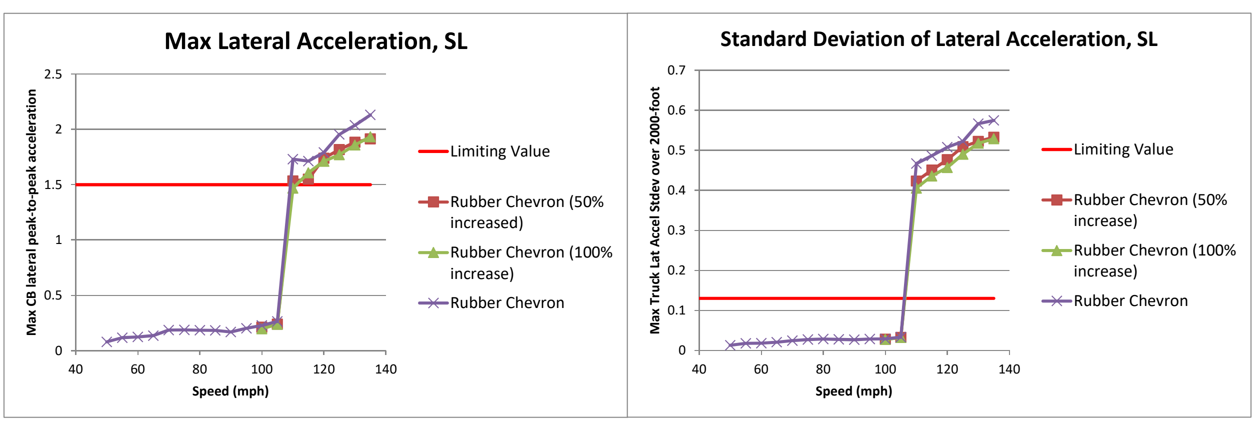

Figure 39. High-Speed Stability, Longitudinal Stiffness Parameter Variation, RTT Tangent Track

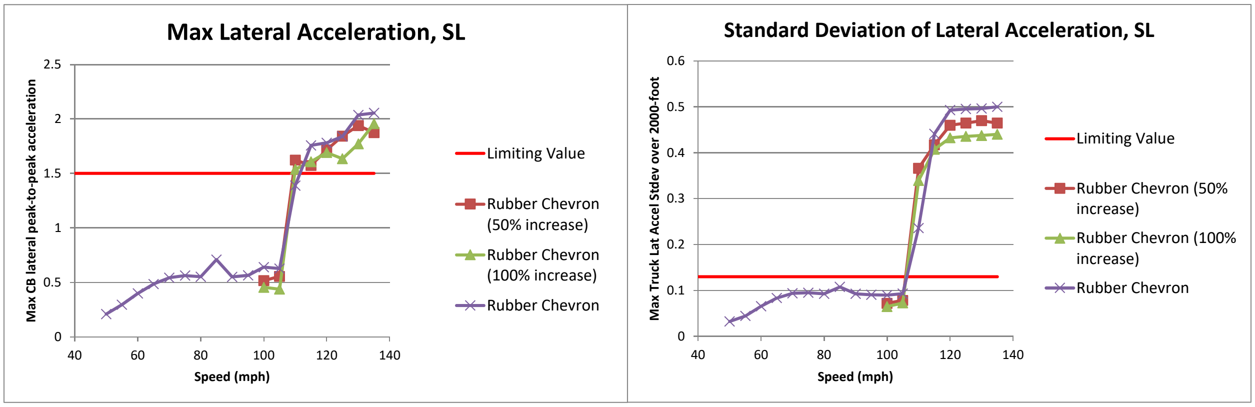

Figure 40. High-Speed Stability, Longitudinal Stiffness Parameter Variation, RTT North Curve

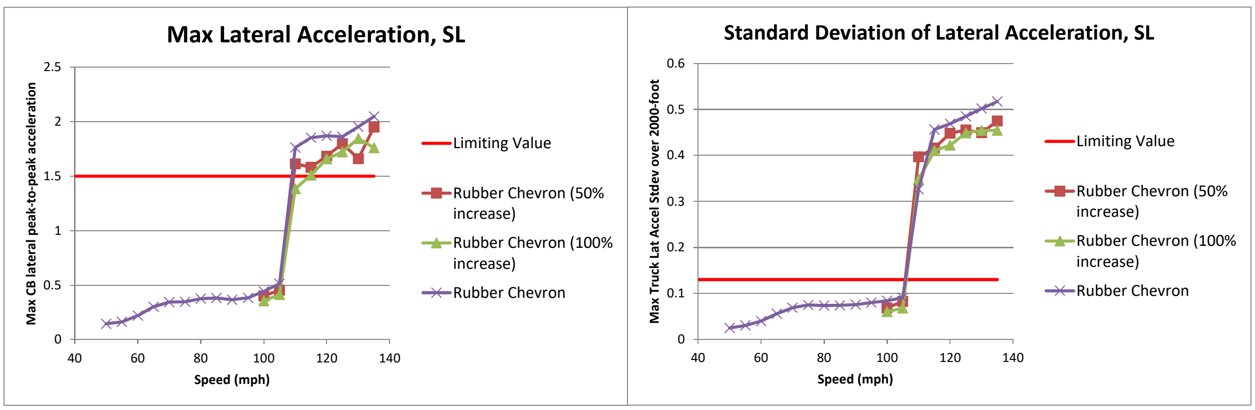

Figure 41. High-Speed Stability, Longitudinal Stiffness Parameter Variation, RTT South Curve

3.14.2 MCAT Results

The results of the MCAT simulations are shown in the following subsections for each truck type. Each subsection shows separate results for each carbody type (single-level and bi-level) as well as two different gage dimensions (56.5-inch and 57.0-inch). All results are based on the 49 CFR § 213.333 performance criteria. Where limits are exceeded, the results are highlighted in red in the respective tables. The reader will note that there are numerous exceedances of the carbody lateral acceleration criterion. This is primarily due to the fact that the secondary suspension characteristics for all truck types evaluated was held constant. It is important to note that the secondary suspension characteristics for each truck suspension evaluated were not tuned to match the primary suspension, as this was beyond the scope of this study.

Conical Spring MCAT Results

Table 15 shows the results for the conical spring suspension under the single-level car with 56.5-inch track gage clearance. The table shows the results for the various wavelength perturbations, three different speed ranges, three different cant deficiencies, and tangent track condition. The results show some exceedances of the wheel L/V ratio, net axle L/V ratio, and truck side L/V ratio. The results also show exceedances for every simulation case of the truck lateral acceleration criteria. This shows poor lateral stability of the truck, probably due to the lateral primary stiffness. There are also numerous exceedances of the carbody lateral acceleration criterion.

Table 16 shows the MCAT results for the conical spring suspension truck for the bi-level car with 56.5-inch gage clearance. The bi-level car does not have any single wheel L/V nor truck side L/V exceedances but still shows some exceedance of the net axle L/V ratio. There are also numerous exceedances of the carbody lateral acceleration criterion.

Table 17 shows the MCAT results for the conical spring suspension truck for the single-level car with 57.0-inch gage clearance. The results show a net axle L/V exceedance for the 31-foot wavelength at 125 mph, and additional exceedances for both the net axle L/V and truck side L/V on the 124-foot wavelength at the highest speeds.

Table 18 shows the MCAT results for the conical spring suspension truck for the bi-level car with 57.0-inch gage clearance. The results show that most of the force results are exceeding on the 124-foot wavelength. There are exceedances of the minimum vertical wheel load, maximum net axle L/V, and maximum truck side L/V.

Table 15. Conical Spring, Single-Level Car, 56.5-inch Gage MCAT Results

Conical Spring, Single-Level Car, 56.5" Gage												
Wavelength	Speed	Cant Deficiency	Min Wheel Vertical Load Ratio (0.15)	Maximum Wheel L/V Ratio (1.13)	Maximum Net Axle L/V Ratio	Maximum Truck Side L/V Ratio (0.6)	Maximum Carbody Lateral Peak to Peak Accel (0.65)	Maximum Carbody Vertical Peak to Peak Accel (1.0)	Carbody Lateral (sustained Oscillatory) (0.10)	Carbody Vertical (sustained Oscillatory) (0.25)	Maximum Truck Lateral Accel (0.3)
31 ft	115 mph	3 in	0.40	0.68	0.63	0.58	0.42	0.28	0.10	0.05	1.30
31 ft	115 mph	4 in	0.39	0.65	0.61	0.55	0.43	0.27	0.10	0.05	1.17
31 ft	115 mph	5 in	0.45	0.57	0.58	0.52	0.52	0.27	0.11	0.05	1.01
31 ft	115 mph	Tangent	0.34	0.66	0.62	0.60	0.33	0.27	0.10	0.05	1.54
31 ft	120 mph	3 in	0.31	1.15	0.67	0.62	0.45	0.29	0.11	0.05	1.56
31 ft	120 mph	4 in	0.30	1.16	0.70	0.62	0.48	0.29	0.12	0.05	1.50
31 ft	120 mph	5 in	0.30	1.16	0.69	0.54	0.48	0.29	0.12	0.05	1.36
31 ft	120 mph	Tangent	0.30	0.75	0.64	0.57	0.35	0.28	0.11	0.05	1.77
31 ft	125 mph	3 in	0.27	0.67	0.67	0.54	0.39	0.30	0.12	0.05	1.71
31 ft	125 mph	4 in	0.31	0.68	0.72	0.57	0.43	0.30	0.13	0.05	1.69
31 ft	125 mph	5 in	0.15	0.93	0.66	0.73	0.50	0.30	0.14	0.05	1.62
31 ft	125 mph	Tangent	0.30	0.69	0.67	0.64	0.35	0.30	0.11	0.05	1.85
62 ft	115 mph	3 in	0.52	0.51	0.53	0.43	0.47	0.33	0.10	0.06	1.14
62 ft	115 mph	4 in	0.49	0.58	0.53	0.33	0.40	0.33	0.10	0.06	0.97
62 ft	115 mph	5 in	0.50	0.48	0.47	0.33	0.69	0.33	0.12	0.06	0.85
62 ft	115 mph	Tangent	0.50	0.56	0.53	0.54	0.56	0.33	0.10	0.06	1.45
62 ft	120 mph	3 in	0.42	0.56	0.58	0.53	0.59	0.31	0.13	0.06	1.40
62 ft	120 mph	4 in	0.41	0.66	0.63	0.49	0.44	0.31	0.12	0.06	1.24
62 ft	120 mph	5 in	0.42	0.58	0.57	0.54	0.56	0.32	0.13	0.06	1.16
62 ft	120 mph	Tangent	0.42	0.61	0.56	0.58	0.50	0.31	0.12	0.06	1.73
62 ft	125 mph	3 in	0.34	0.60	0.67	0.72	0.66	0.30	0.14	0.06	1.69
62 ft	125 mph	4 in	0.36	0.60	0.65	0.63	0.64	0.30	0.15	0.06	1.67
62 ft	125 mph	5 in	0.33	0.58	0.69	0.70	0.49	0.30	0.14	0.06	1.54
62 ft	125 mph	Tangent	0.39	0.66	0.60	0.65	0.46	0.30	0.12	0.06	1.80
124 ft	115 mph	3 in	0.41	0.70	0.64	0.53	1.18	0.74	0.21	0.17	1.25
124 ft	115 mph	4 in	0.34	0.63	0.59	0.50	1.22	0.74	0.21	0.17	1.08
124 ft	115 mph	5 in	0.42	0.56	0.53	0.46	1.06	0.74	0.19	0.17	1.01
124 ft	115 mph	Tangent	0.50	0.53	0.53	0.51	1.16	0.73	0.17	0.17	1.49
124 ft	120 mph	3 in	0.35	0.62	0.61	0.56	1.09	0.92	0.20	0.21	1.51
124 ft	120 mph	4 in	0.29	0.69	0.66	0.54	1.20	0.92	0.23	0.21	1.34
124 ft	120 mph	5 in	0.28	0.63	0.61	0.54	1.24	0.92	0.21	0.21	1.22
124 ft	120 mph	Tangent	0.19	0.63	0.60	0.57	1.09	0.91	0.21	0.21	1.77
124 ft	125 mph	3 in	0.19	0.67	0.67	0.66	1.17	1.09	0.24	0.24	1.76
124 ft	125 mph	4 in	0.18	0.62	0.64	0.68	1.10	1.10	0.24	0.24	1.70
124 ft	125 mph	5 in	0.25	0.62	0.70	0.63	1.14	1.09	0.22	0.24	1.57
124 ft	125 mph	Tangent	0.22	0.64	0.64	0.65	1.26	1.07	0.26	0.24	1.85

Table 16. Conical Spring, Bi-Level Car, 56.5-inch Gage MCAT Results

Conical Spring, Bi-Level Car, 56.5" Gage											
Wavelength	Speed	Cant Deficiency	Min Wheel Vertical Load Ratio (0.15)	Maximum Wheel L/V Ratio (1.13)	Maximum Net Axle L/V Ratio	Maximum Truck Side L/V Ratio (0.6)	Maximum Carbody Lateral Peak to Peak Accel (0.65)	Maximum Carbody Vertical Peak to Peak Accel (1.0)	Carbody Lateral (sustained Oscillatory) (0.10)	Carbody Vertical (sustained Oscillatory) (0.25)	Maximum Truck Lateral Accel (0.3)
31 ft	115 mph	3 in	0.46	0.40	0.50	0.47	0.38	0.21	0.11	0.04	1.57
31 ft	115 mph	4 in	0.44	0.41	0.47	0.52	0.37	0.21	0.11	0.04	1.49
31 ft	115 mph	5 in	0.43	0.51	0.48	0.49	0.47	0.21	0.10	0.04	1.25
31 ft	115 mph	Tangent	0.56	0.44	0.43	0.52	0.31	0.21	0.11	0.04	1.90
31 ft	120 mph	3 in	0.36	0.47	0.50	0.57	0.35	0.22	0.11	0.04	2.00
31 ft	120 mph	4 in	0.40	0.49	0.54	0.56	0.43	0.23	0.12	0.04	1.72
31 ft	120 mph	5 in	0.31	0.47	0.50	0.52	0.50	0.22	0.13	0.04	1.55
31 ft	120 mph	Tangent	0.53	0.48	0.50	0.54	0.34	0.22	0.12	0.04	2.25
31 ft	125 mph	3 in	0.38	0.48	0.50	0.58	0.38	0.24	0.14	0.05	2.25
31 ft	125 mph	4 in	0.41	0.50	0.60	0.54	0.46	0.24	0.14	0.05	2.09
31 ft	125 mph	5 in	0.28	0.53	0.59	0.48	0.54	0.23	0.15	0.05	1.86
31 ft	125 mph	Tangent	0.45	0.49	0.53	0.56	0.32	0.24	0.13	0.05	2.59
62 ft	115 mph	3 in	0.45	0.49	0.51	0.37	0.37	0.21	0.11	0.05	1.61
62 ft	115 mph	4 in	0.44	0.38	0.37	0.30	0.43	0.22	0.11	0.05	1.29
62 ft	115 mph	5 in	0.44	0.42	0.40	0.29	0.56	0.22	0.10	0.05	1.06
62 ft	115 mph	Tangent	0.55	0.38	0.40	0.43	0.40	0.21	0.11	0.05	1.77
62 ft	120 mph	3 in	0.44	0.42	0.47	0.46	0.44	0.22	0.13	0.05	1.89
62 ft	120 mph	4 in	0.40	0.49	0.55	0.45	0.40	0.22	0.12	0.04	1.79
62 ft	120 mph	5 in	0.36	0.46	0.46	0.41	0.49	0.22	0.13	0.04	1.52
62 ft	120 mph	Tangent	0.52	0.44	0.45	0.48	0.44	0.23	0.12	0.04	2.21
62 ft	125 mph	3 in	0.41	0.51	0.55	0.51	0.41	0.24	0.13	0.04	2.22
62 ft	125 mph	4 in	0.37	0.46	0.53	0.47	0.46	0.24	0.13	0.04	1.99
62 ft	125 mph	5 in	0.35	0.42	0.47	0.41	0.64	0.24	0.15	0.04	1.72
62 ft	125 mph	Tangent	0.50	0.47	0.49	0.53	0.43	0.23	0.14	0.04	2.48
124 ft	115 mph	3 in	0.23	0.62	0.58	0.51	1.33	1.01	0.29	0.23	1.53
124 ft	115 mph	4 in	0.20	0.64	0.61	0.54	1.24	1.03	0.28	0.24	1.42
124 ft	115 mph	5 in	0.16	0.63	0.60	0.55	1.21	1.04	0.28	0.24	1.28
124 ft	115 mph	Tangent	0.45	0.40	0.40	0.38	1.08	0.98	0.24	0.23	1.75
124 ft	120 mph	3 in	0.23	0.63	0.60	0.52	1.24	1.07	0.29	0.24	2.06
124 ft	120 mph	4 in	0.07	0.66	0.63	0.57	1.38	1.09	0.29	0.25	1.88
124 ft	120 mph	5 in	0.04	0.66	0.63	0.56	1.31	1.09	0.29	0.25	1.57
124 ft	120 mph	Tangent	0.41	0.57	0.52	0.46	1.48	1.03	0.29	0.23	2.34
124 ft	125 mph	3 in	0.26	0.57	0.56	0.51	1.48	1.09	0.30	0.25	2.33
124 ft	125 mph	4 in	0.25	0.59	0.63	0.57	1.46	1.10	0.28	0.25	2.09
124 ft	125 mph	5 in	0.15	0.66	0.63	0.54	1.32	1.12	0.29	0.25	1.82
124 ft	125 mph	Tangent	0.32	0.55	0.53	0.51	1.41	1.01	0.28	0.23	2.62

Table 17. Conical Spring, Single-Level Car, 57.0-inch Gage MCAT Results

Conical Spring, Single-Level Car, 57.0" Gage											
Wavelength	Speed	Cant Deficiency	Min Wheel Vertical Load Ratio (0.15)	Maximum Wheel L/V Ratio (1.13)	Maximum Net Axle L/V Ratio	Maximum Truck Side L/V Ratio (0.6)	Maximum Carbody Lateral Peak to Peak Accel (0.65)	Maximum Carbody Vertical Peak to Peak Accel (1.0)	Carbody Lateral (sustained Oscillatory) (0.10)	Carbody Vertical (sustained Oscillatory) (0.25)	Maximum Truck Lateral Accel (0.3)
31 ft	115 mph	3 in	0.61	0.51	0.53	0.37	0.78	0.27	0.11	0.05	0.42
31 ft	115 mph	4 in	0.57	0.51	0.55	0.38	0.90	0.27	0.14	0.05	0.41
31 ft	115 mph	5 in	0.52	0.55	0.57	0.39	0.81	0.27	0.13	0.05	0.39
31 ft	120 mph	3 in	0.55	0.53	0.56	0.39	0.77	0.28	0.11	0.05	0.46
31 ft	120 mph	4 in	0.52	0.58	0.54	0.36	0.67	0.29	0.10	0.05	0.48
31 ft	120 mph	5 in	0.48	0.56	0.54	0.40	0.82	0.28	0.14	0.05	0.46
31 ft	125 mph	3 in	0.54	0.61	0.55	0.35	0.66	0.30	0.09	0.05	0.53
31 ft	125 mph	4 in	0.41	0.57	0.54	0.39	0.75	0.30	0.12	0.05	0.51
31 ft	125 mph	5 in	0.44	0.63	0.65	0.44	1.00	0.30	0.18	0.05	0.53
62 ft	115 mph	3 in	0.61	0.44	0.42	0.25	0.70	0.33	0.10	0.06	0.37
62 ft	115 mph	4 in	0.57	0.48	0.46	0.30	0.85	0.33	0.13	0.06	0.35
62 ft	115 mph	5 in	0.51	0.55	0.52	0.31	0.78	0.33	0.12	0.06	0.44
62 ft	120 mph	3 in	0.62	0.52	0.48	0.30	0.67	0.32	0.10	0.06	0.44
62 ft	120 mph	4 in	0.55	0.49	0.47	0.32	0.88	0.32	0.14	0.06	0.41
62 ft	120 mph	5 in	0.53	0.44	0.45	0.31	0.70	0.31	0.12	0.06	0.42
62 ft	125 mph	3 in	0.59	0.46	0.44	0.28	0.72	0.30	0.11	0.06	0.42
62 ft	125 mph	4 in	0.54	0.42	0.41	0.28	0.73	0.30	0.12	0.06	0.43
62 ft	125 mph	5 in	0.49	0.53	0.52	0.34	0.86	0.30	0.15	0.06	0.44
124 ft	115 mph	3 in	0.38	0.55	0.51	0.45	1.23	0.74	0.25	0.17	0.37
124 ft	115 mph	4 in	0.35	0.60	0.55	0.50	1.22	0.74	0.26	0.17	0.41
124 ft	115 mph	5 in	0.34	0.64	0.61	0.56	1.29	0.74	0.26	0.17	0.34
124 ft	120 mph	3 in	0.36	0.57	0.53	0.47	1.41	0.92	0.27	0.21	0.75
124 ft	120 mph	4 in	0.30	0.64	0.61	0.62	1.58	0.92	0.32	0.21	0.71
124 ft	120 mph	5 in	0.25	0.63	0.65	0.67	1.51	0.93	0.30	0.21	0.44
124 ft	125 mph	3 in	0.33	0.65	0.64	0.60	1.91	1.10	0.34	0.24	0.77
124 ft	125 mph	4 in	0.24	0.70	0.72	0.72	2.01	1.09	0.36	0.24	0.81
124 ft	125 mph	5 in	0.23	0.67	0.72	0.73	1.63	1.09	0.33	0.24	0.49

Table 18. Conical Spring, Bi-Level Car, 57.0-inch Gage MCAT Results

57.0 G Curves and Tangent											
Wavelength	Speed	Cant Deficiency	Min Wheel Vertical Load Ratio (0.15)	Maximum Wheel L/V Ratio (1.13)	Maximum Net Axle L/V Ratio	Maximum Truck Side L/V Ratio (0.6)	Maximum Carbody Lateral Peak to Peak Accel (0.65)	Maximum Carbody Vertical Peak to Peak Accel (1.0)	Carbody Lateral (sustained Oscillatory) (0.10)	Carbody Vertical (sustained Oscillatory) (0.25)	Maximum Carbody Truck Lateral Accel (0.3)
31 ft	115 mph	3 in	0.57	0.31	0.34	0.23	0.54	0.21	0.09	0.04	0.39
31 ft	115 mph	4 in	0.53	0.32	0.34	0.23	0.50	0.21	0.09	0.04	0.40
31 ft	115 mph	5 in	0.47	0.36	0.36	0.26	0.58	0.21	0.11	0.04	0.40
31 ft	120 mph	3 in	0.55	0.33	0.34	0.23	0.51	0.22	0.08	0.04	0.43
31 ft	120 mph	4 in	0.48	0.34	0.37	0.25	0.54	0.22	0.09	0.04	0.45
31 ft	120 mph	5 in	0.42	0.37	0.38	0.28	0.56	0.22	0.11	0.04	0.47
31 ft	125 mph	3 in	0.61	0.32	0.35	0.23	0.42	0.24	0.06	0.05	0.48
31 ft	125 mph	4 in	0.51	0.35	0.39	0.28	0.60	0.24	0.10	0.05	0.48
31 ft	125 mph	5 in	0.46	0.37	0.41	0.29	0.60	0.24	0.11	0.05	0.53
62 ft	115 mph	3 in	0.56	0.32	0.30	0.25	0.53	0.21	0.09	0.05	0.32
62 ft	115 mph	4 in	0.57	0.30	0.29	0.26	0.50	0.21	0.09	0.05	0.35
62 ft	115 mph	5 in	0.48	0.38	0.36	0.33	0.63	0.21	0.12	0.05	0.33
62 ft	120 mph	3 in	0.59	0.31	0.30	0.26	0.53	0.22	0.10	0.04	0.35
62 ft	120 mph	4 in	0.55	0.34	0.34	0.27	0.52	0.23	0.10	0.05	0.38
62 ft	120 mph	5 in	0.46	0.35	0.33	0.33	0.57	0.22	0.10	0.04	0.39
62 ft	125 mph	3 in	0.61	0.28	0.27	0.19	0.40	0.23	0.07	0.04	0.41
62 ft	125 mph	4 in	0.54	0.34	0.33	0.29	0.55	0.23	0.11	0.04	0.40
62 ft	125 mph	5 in	0.47	0.35	0.36	0.31	0.51	0.23	0.11	0.04	0.46
124 ft	115 mph	3 in	0.25	0.63	0.60	0.63	1.60	1.02	0.41	0.23	0.52
124 ft	115 mph	4 in	0.03	0.67	0.75	0.70	1.66	1.02	0.47	0.24	0.60
124 ft	115 mph	5 in	0.09	0.64	0.62	0.58	1.32	1.04	0.38	0.24	0.37
124 ft	120 mph	3 in	0.09	0.65	0.62	0.62	1.66	1.07	0.40	0.24	0.54
124 ft	120 mph	4 in	0.08	0.66	0.63	0.65	1.63	1.08	0.43	0.25	0.49
124 ft	120 mph	5 in	0.05	0.68	0.65	0.68	1.55	1.09	0.41	0.25	0.44
124 ft	125 mph	3 in	0.02	0.70	0.82	0.81	1.90	1.08	0.41	0.24	0.57
124 ft	125 mph	4 in	0.01	0.72	0.67	0.69	1.65	1.10	0.46	0.25	0.58
124 ft	125 mph	5 in	0.01	0.73	0.71	0.71	1.61	1.12	0.43	0.26	0.56

Equalizer Beam MCAT Results

Table 19 shows the results for the equalizer beam suspension under the single-level car with 56.5-inch track gage clearance. The results show no exceedances of the wheel-rail force L/V outputs. All exceedances are of the carbody lateral acceleration criterion output, with a few exceedances of the lateral truck acceleration. In general, results show the equalizer beam truck is more laterally stable then the conical spring truck.

Table 20 shows the results of the 56.5-inch track gage for the bi-level car. The results show exceedances of the net axle L/V ratio at the 124-foot wavelength regimes. All other exceedances are of the carbody lateral accelerations.

Table 21 shows the single-level car results for the 57.0-inch regimes, where there are a few exceedances of the net axle L/V ratio, but no exceedance of the truck lateral acceleration.

Table 22 shows results for the 57.0-inch track gage regime for the bi-level car. These results are similar to the single-level car results shown in Table 21.

Table 19. Equalizer Beam, Single-Level Car, 56.5-inch Gage MCAT Results

Equalizer Beam, Single-Level Car, 56.5" Gage											
Wavelength	Speed	Cant Deficiency	Min Wheel Vertical Load Ratio (0.15)	Maximum Wheel L/V Ratio (1.13)	Maximum Net Axle L/V Ratio	Maximum Truck Side L/V Ratio (0.6)	Maximum Carbody Lateral Peak to Peak Accel (0.65)	Maximum Carbody Vertical Peak to Peak Accel (1.0)	Carbody Lateral (sustained Oscillatory) (0.10)	Carbody Vertical (sustained Oscillatory) (0.25)	Maximum Truck Lateral Accel (0.3)
31 ft	115 mph	3 in	0.28	0.43	0.44	0.32	0.24	0.37	0.04	0.06	0.21
31 ft	115 mph	4 in	0.26	0.43	0.45	0.32	0.25	0.37	0.04	0.06	0.19
31 ft	115 mph	5 in	0.25	0.45	0.46	0.33	0.25	0.37	0.04	0.06	0.19
31 ft	115 mph	Tangent	0.28	0.47	0.39	0.40	0.26	0.39	0.07	0.07	0.47
31 ft	120 mph	3 in	0.24	0.45	0.46	0.33	0.26	0.40	0.04	0.08	0.28
31 ft	120 mph	4 in	0.22	0.46	0.47	0.33	0.28	0.40	0.04	0.08	0.24
31 ft	120 mph	5 in	0.20	0.48	0.48	0.34	0.29	0.40	0.04	0.08	0.22
31 ft	120 mph	Tangent	0.23	0.58	0.38	0.38	0.27	0.41	0.07	0.08	0.50
31 ft	125 mph	3 in	0.18	0.55	0.47	0.45	0.27	0.43	0.07	0.09	0.46
31 ft	125 mph	4 in	0.22	0.48	0.49	0.34	0.29	0.43	0.05	0.08	0.36
31 ft	125 mph	5 in	0.21	0.50	0.50	0.35	0.32	0.43	0.05	0.08	0.28
31 ft	125 mph	Tangent	0.20	0.73	0.54	0.46	0.28	0.43	0.08	0.08	0.57
62 ft	115 mph	3 in	0.53	0.43	0.42	0.29	0.30	0.35	0.04	0.06	0.19
62 ft	115 mph	4 in	0.51	0.43	0.43	0.29	0.33	0.35	0.05	0.06	0.19
62 ft	115 mph	5 in	0.48	0.45	0.44	0.30	0.35	0.35	0.05	0.06	0.19
62 ft	115 mph	Tangent	0.53	0.47	0.42	0.45	0.37	0.36	0.08	0.06	0.47
62 ft	120 mph	3 in	0.50	0.45	0.44	0.33	0.33	0.34	0.05	0.05	0.29
62 ft	120 mph	4 in	0.48	0.46	0.45	0.33	0.37	0.34	0.05	0.06	0.24
62 ft	120 mph	5 in	0.45	0.47	0.47	0.32	0.39	0.34	0.06	0.06	0.20
62 ft	120 mph	Tangent	0.54	0.54	0.45	0.45	0.35	0.35	0.08	0.06	0.53
62 ft	125 mph	3 in	0.48	0.57	0.50	0.48	0.38	0.33	0.09	0.06	0.48
62 ft	125 mph	4 in	0.44	0.49	0.47	0.36	0.38	0.33	0.07	0.06	0.40
62 ft	125 mph	5 in	0.41	0.51	0.48	0.36	0.43	0.33	0.06	0.06	0.30
62 ft	125 mph	Tangent	0.51	0.57	0.52	0.48	0.58	0.34	0.10	0.06	0.58
124 ft	115 mph	3 in	0.51	0.46	0.42	0.32	0.80	0.56	0.15	0.13	0.19
124 ft	115 mph	4 in	0.42	0.50	0.47	0.38	0.83	0.56	0.15	0.14	0.21
124 ft	115 mph	5 in	0.38	0.55	0.53	0.45	0.84	0.56	0.15	0.13	0.23
124 ft	115 mph	Tangent	0.62	0.42	0.35	0.28	0.75	0.56	0.13	0.13	0.43
124 ft	120 mph	3 in	0.48	0.48	0.44	0.35	0.87	0.67	0.16	0.16	0.21
124 ft	120 mph	4 in	0.41	0.54	0.51	0.42	0.88	0.67	0.16	0.16	0.25
124 ft	120 mph	5 in	0.34	0.62	0.57	0.48	0.94	0.67	0.17	0.16	0.26
124 ft	120 mph	Tangent	0.43	0.50	0.41	0.35	0.77	0.67	0.15	0.16	0.50
124 ft	125 mph	3 in	0.48	0.47	0.46	0.36	0.90	0.78	0.16	0.18	0.24
124 ft	125 mph	4 in	0.41	0.55	0.51	0.42	0.95	0.78	0.18	0.18	0.28
124 ft	125 mph	5 in	0.34	0.65	0.58	0.49	1.02	0.78	0.18	0.18	0.29
124 ft	125 mph	Tangent	0.39	0.55	0.44	0.43	0.78	0.79	0.14	0.18	0.55

Table 20. Equalizer Beam, Bi-Level Car, 56.5-inch Gage MCAT Results

Equalizer Beam, Bi-Level Car, 56.5" Gage											
Wavelength	Speed	Cant Deficiency	Min Wheel Vertical Load Ratio (0.15)	Maximum Wheel L/V Ratio (1.13)	Maximum Net Axle L/V Ratio	Maximum Truck Side L/V Ratio (0.6)	Maximum Carbody Lateral Peak to Peak Accel (0.65)	Maximum Carbody Vertical Peak to Peak Accel (1.0)	Carbody Lateral (sustained Oscillatory) (0.10)	Carbody Vertical (sustained Oscillatory) (0.25)	Maximum Truck Lateral Accel (0.3)
31 ft	115 mph	3 in	0.52	0.33	0.33	0.22	0.19	0.25	0.03	0.05	0.20
31 ft	115 mph	4 in	0.48	0.34	0.35	0.24	0.22	0.25	0.03	0.05	0.20
31 ft	115 mph	5 in	0.44	0.34	0.36	0.24	0.25	0.25	0.04	0.05	0.20
31 ft	115 mph	Tangent	0.62	0.17	0.16	0.11	0.19	0.25	0.03	0.05	0.17
31 ft	120 mph	3 in	0.50	0.34	0.35	0.23	0.19	0.28	0.03	0.05	0.20
31 ft	120 mph	4 in	0.46	0.35	0.37	0.24	0.21	0.28	0.03	0.05	0.20
31 ft	120 mph	5 in	0.42	0.36	0.38	0.25	0.23	0.28	0.04	0.05	0.20
31 ft	120 mph	Tangent	0.60	0.20	0.21	0.14	0.18	0.28	0.03	0.05	0.23
31 ft	125 mph	3 in	0.48	0.35	0.36	0.23	0.19	0.32	0.03	0.06	0.20
31 ft	125 mph	4 in	0.44	0.37	0.38	0.24	0.21	0.32	0.03	0.06	0.20
31 ft	125 mph	5 in	0.40	0.38	0.40	0.26	0.24	0.32	0.04	0.06	0.20
31 ft	125 mph	Tangent	0.52	0.28	0.25	0.22	0.18	0.32	0.06	0.06	0.48
62 ft	115 mph	3 in	0.60	0.33	0.33	0.21	0.25	0.24	0.05	0.04	0.20
62 ft	115 mph	4 in	0.54	0.33	0.35	0.22	0.27	0.24	0.06	0.04	0.20
62 ft	115 mph	5 in	0.50	0.34	0.36	0.23	0.29	0.24	0.06	0.04	0.20
62 ft	115 mph	Tangent	0.80	0.19	0.18	0.15	0.26	0.24	0.05	0.04	0.25
62 ft	120 mph	3 in	0.56	0.34	0.36	0.23	0.24	0.23	0.05	0.04	0.20
62 ft	120 mph	4 in	0.52	0.35	0.37	0.23	0.26	0.23	0.06	0.04	0.20
62 ft	120 mph	5 in	0.47	0.37	0.38	0.25	0.29	0.23	0.06	0.04	0.20
62 ft	120 mph	Tangent	0.79	0.22	0.21	0.20	0.25	0.23	0.05	0.04	0.35
62 ft	125 mph	3 in	0.54	0.35	0.36	0.22	0.22	0.23	0.05	0.04	0.20
62 ft	125 mph	4 in	0.50	0.37	0.38	0.24	0.25	0.23	0.05	0.04	0.20
62 ft	125 mph	5 in	0.45	0.38	0.40	0.26	0.29	0.23	0.06	0.04	0.20
62 ft	125 mph	Tangent	0.64	0.35	0.32	0.30	0.35	0.23	0.08	0.04	0.53
124 ft	115 mph	3 in	0.49	0.52	0.47	0.39	0.87	0.73	0.17	0.17	0.20
124 ft	115 mph	4 in	0.43	0.60	0.54	0.45	0.89	0.73	0.18	0.17	0.20
124 ft	115 mph	5 in	0.37	0.64	0.58	0.50	0.89	0.73	0.18	0.17	0.22
124 ft	115 mph	Tangent	0.56	0.26	0.25	0.24	0.90	0.73	0.17	0.17	0.16
124 ft	120 mph	3 in	0.48	0.52	0.47	0.39	0.90	0.79	0.18	0.18	0.21
124 ft	120 mph	4 in	0.40	0.64	0.57	0.47	0.93	0.79	0.19	0.18	0.23
124 ft	120 mph	5 in	0.34	0.68	0.61	0.51	0.94	0.79	0.19	0.18	0.25
124 ft	120 mph	Tangent	0.59	0.26	0.25	0.24	0.88	0.79	0.17	0.18	0.17
124 ft	125 mph	3 in	0.48	0.49	0.44	0.37	0.90	0.83	0.18	0.19	0.24
124 ft	125 mph	4 in	0.41	0.61	0.55	0.46	0.95	0.83	0.19	0.19	0.26
124 ft	125 mph	5 in	0.32	0.69	0.62	0.51	0.99	0.83	0.20	0.19	0.28
124 ft	125 mph	Tangent	0.60	0.30	0.28	0.23	0.83	0.83	0.17	0.19	0.19

Table 21. Equalizer Beam, Single-Level Car, 57.0-inch Gage MCAT Results

Equalizer Beam, Single-Level Car, 57.0" Gage											
Wavelength	Speed	Cant Deficiency	Min Wheel Vertical Load Ratio (0.15)	Maximum Wheel L/V Ratio (1.13)	Maximum Net Axle L/V Ratio	Maximum Truck Side L/V Ratio (0.6)	Maximum Carbody Lateral Peak to Peak Accel (0.65)	Maximum Carbody Vertical Peak to Peak Accel (1.0)	Carbody Lateral (sustained Oscillatory) (0.10)	Carbody Vertical (sustained Oscillatory) (0.25)	Maximum Truck Lateral Accel (0.3)
31 ft	115 mph	3 in	0.28	0.42	0.43	0.29	0.27	0.37	0.04	0.06	0.18
31 ft	115 mph	4 in	0.25	0.43	0.43	0.31	0.30	0.37	0.05	0.06	0.18
31 ft	115 mph	5 in	0.23	0.44	0.45	0.32	0.34	0.37	0.06	0.06	0.18
31 ft	120 mph	3 in	0.24	0.44	0.44	0.31	0.27	0.40	0.04	0.08	0.19
31 ft	120 mph	4 in	0.22	0.45	0.46	0.32	0.28	0.40	0.05	0.08	0.18
31 ft	120 mph	5 in	0.19	0.46	0.48	0.33	0.32	0.40	0.06	0.08	0.18
31 ft	125 mph	3 in	0.23	0.46	0.47	0.33	0.30	0.43	0.05	0.08	0.20
31 ft	125 mph	4 in	0.22	0.47	0.48	0.32	0.30	0.43	0.05	0.08	0.19
31 ft	125 mph	5 in	0.21	0.48	0.49	0.34	0.33	0.43	0.06	0.08	0.19
62 ft	115 mph	3 in	0.56	0.41	0.41	0.25	0.32	0.35	0.05	0.06	0.16
62 ft	115 mph	4 in	0.53	0.43	0.43	0.27	0.35	0.35	0.06	0.06	0.17
62 ft	115 mph	5 in	0.49	0.44	0.44	0.28	0.37	0.35	0.06	0.06	0.17
62 ft	120 mph	3 in	0.51	0.44	0.43	0.27	0.37	0.34	0.06	0.05	0.16
62 ft	120 mph	4 in	0.49	0.45	0.44	0.28	0.38	0.34	0.06	0.05	0.17
62 ft	120 mph	5 in	0.46	0.46	0.46	0.29	0.40	0.34	0.07	0.05	0.17
62 ft	125 mph	3 in	0.49	0.46	0.44	0.27	0.41	0.33	0.06	0.06	0.17
62 ft	125 mph	4 in	0.46	0.47	0.46	0.29	0.43	0.33	0.07	0.06	0.16
62 ft	125 mph	5 in	0.42	0.48	0.48	0.30	0.44	0.33	0.07	0.06	0.17
124 ft	115 mph	3 in	0.44	0.46	0.42	0.34	0.87	0.56	0.16	0.13	0.19
124 ft	115 mph	4 in	0.35	0.52	0.52	0.47	0.89	0.56	0.17	0.14	0.21
124 ft	115 mph	5 in	0.29	0.58	0.59	0.54	0.97	0.56	0.17	0.14	0.22
124 ft	120 mph	3 in	0.45	0.45	0.43	0.33	1.01	0.67	0.17	0.16	0.19
124 ft	120 mph	4 in	0.34	0.53	0.53	0.45	0.98	0.67	0.17	0.16	0.24
124 ft	120 mph	5 in	0.28	0.60	0.61	0.50	1.11	0.67	0.18	0.16	0.26
124 ft	125 mph	3 in	0.48	0.46	0.44	0.32	1.06	0.78	0.17	0.18	0.19
124 ft	125 mph	4 in	0.39	0.50	0.46	0.38	1.11	0.78	0.18	0.18	0.25
124 ft	125 mph	5 in	0.26	0.62	0.62	0.52	1.24	0.78	0.20	0.18	0.29

Table 22. Equalizer Beam, Bi-Level Car, 57.0-inch Gage MCAT Results

Equalizer Beam, Bi-Level Car, 57.0" Gage											
Wavelength	Speed	Cant Deficiency	Min Wheel Vertical Load Ratio (0.15)	Maximum Wheel L/V Ratio (1.13)	Maximum Net Axle L/V Ratio	Maximum Truck Side L/V Ratio (0.6)	Maximum Carbody Lateral Peak to Peak Accel (0.65)	Maximum Carbody Vertical Peak to Peak Accel (1.0)	Carbody Lateral (sustained Oscillatory) (0.10)	Carbody Vertical (sustained Oscillatory) (0.25)	Maximum Truck Lateral Accel (0.3)
31 ft	115 mph	3 in	0.52	0.32	0.32	0.20	0.21	0.25	0.04	0.05	0.19
31 ft	115 mph	4 in	0.47	0.34	0.35	0.22	0.24	0.25	0.05	0.05	0.19
31 ft	115 mph	5 in	0.43	0.35	0.37	0.24	0.26	0.25	0.06	0.05	0.18
31 ft	120 mph	3 in	0.50	0.34	0.34	0.23	0.22	0.28	0.04	0.05	0.19
31 ft	120 mph	4 in	0.46	0.35	0.35	0.22	0.23	0.28	0.05	0.05	0.19
31 ft	120 mph	5 in	0.41	0.37	0.38	0.24	0.25	0.28	0.06	0.05	0.19
31 ft	125 mph	3 in	0.48	0.36	0.35	0.24	0.23	0.32	0.04	0.06	0.21
31 ft	125 mph	4 in	0.44	0.36	0.37	0.24	0.24	0.32	0.05	0.06	0.20
31 ft	125 mph	5 in	0.39	0.38	0.39	0.24	0.26	0.32	0.06	0.06	0.18
62 ft	115 mph	3 in	0.61	0.32	0.32	0.19	0.26	0.24	0.06	0.04	0.19
62 ft	115 mph	4 in	0.55	0.34	0.36	0.21	0.29	0.24	0.06	0.04	0.19
62 ft	115 mph	5 in	0.50	0.35	0.37	0.23	0.30	0.24	0.07	0.04	0.19
62 ft	120 mph	3 in	0.57	0.34	0.34	0.19	0.24	0.23	0.05	0.04	0.19
62 ft	120 mph	4 in	0.54	0.35	0.35	0.20	0.27	0.23	0.06	0.04	0.20
62 ft	120 mph	5 in	0.48	0.36	0.38	0.23	0.30	0.23	0.07	0.04	0.19
62 ft	125 mph	3 in	0.55	0.36	0.35	0.20	0.23	0.23	0.05	0.04	0.19
62 ft	125 mph	4 in	0.51	0.36	0.37	0.21	0.25	0.23	0.06	0.04	0.19
62 ft	125 mph	5 in	0.46	0.37	0.38	0.22	0.30	0.24	0.07	0.04	0.19
124 ft	115 mph	3 in	0.46	0.57	0.50	0.49	1.13	0.73	0.25	0.17	0.20
124 ft	115 mph	4 in	0.39	0.62	0.54	0.49	1.06	0.73	0.23	0.17	0.20
124 ft	115 mph	5 in	0.34	0.64	0.59	0.51	1.04	0.73	0.22	0.17	0.20
124 ft	120 mph	3 in	0.45	0.59	0.51	0.50	1.10	0.79	0.25	0.18	0.22
124 ft	120 mph	4 in	0.39	0.64	0.56	0.52	1.10	0.79	0.24	0.18	0.22
124 ft	120 mph	5 in	0.32	0.68	0.62	0.54	1.13	0.79	0.23	0.18	0.23
124 ft	125 mph	3 in	0.46	0.60	0.52	0.51	1.13	0.83	0.26	0.19	0.23
124 ft	125 mph	4 in	0.35	0.67	0.58	0.55	1.13	0.83	0.26	0.19	0.25
124 ft	125 mph	5 in	0.28	0.70	0.66	0.58	1.16	0.83	0.25	0.19	0.25

Journal Spring MCAT Results

Table 23 through Table 26 show all MCAT results for the journal spring trucks. The most important observations of these results are that none of the force output (L/V ratios) nor truck lateral accelerations show any exceedances. All exceedances are of the carbody lateral acceleration criterion.

Table 23. Journal Spring, Single-Level Car, 56.5-inch Gage MCAT Results

Journal Spring, Single-Level Car, 56.5" Gage											
Wavelength	Speed	Cant Deficiency	Min Wheel Vertical Load Ratio (0.15)	Maximum Wheel L/V Ratio (1.13)	Maximum Net Axle L/V Ratio	Maximum Truck Side L/V Ratio (0.6)	Maximum Carbody Lateral Peak to Peak Accel (0.65)	Maximum Carbody Vertical Peak to Peak Accel (1.0)	Carbody Lateral (sustained Oscillatory) (0.10)	Carbody Vertical (sustained Oscillatory) (0.25)	Maximum Truck Lateral Accel (0.3)
31 ft	115 mph	3 in	0.54	0.38	0.41	0.23	0.24	0.22	0.04	0.03	0.17
31 ft	115 mph	4 in	0.51	0.40	0.43	0.26	0.24	0.22	0.04	0.03	0.17
31 ft	115 mph	5 in	0.48	0.43	0.46	0.28	0.24	0.22	0.04	0.03	0.17
31 ft	115 mph	Tangent	0.56	0.26	0.28	0.19	0.22	0.23	0.06	0.04	0.16
31 ft	120 mph	3 in	0.51	0.41	0.43	0.26	0.24	0.22	0.04	0.03	0.18
31 ft	120 mph	4 in	0.48	0.43	0.45	0.27	0.24	0.23	0.04	0.03	0.17
31 ft	120 mph	5 in	0.45	0.44	0.48	0.29	0.25	0.23	0.04	0.03	0.17
31 ft	120 mph	Tangent	0.56	0.37	0.40	0.24	0.29	0.24	0.07	0.04	0.19
31 ft	125 mph	3 in	0.49	0.43	0.47	0.28	0.25	0.23	0.04	0.04	0.20
31 ft	125 mph	4 in	0.45	0.45	0.48	0.30	0.26	0.23	0.04	0.04	0.20
31 ft	125 mph	5 in	0.42	0.47	0.49	0.30	0.25	0.23	0.04	0.04	0.20
31 ft	125 mph	Tangent	0.48	0.36	0.30	0.19	0.24	0.24	0.05	0.04	0.16
62 ft	115 mph	3 in	0.55	0.37	0.40	0.22	0.27	0.37	0.05	0.06	0.17
62 ft	115 mph	4 in	0.52	0.39	0.42	0.23	0.26	0.37	0.05	0.06	0.17
62 ft	115 mph	5 in	0.48	0.41	0.44	0.25	0.25	0.37	0.05	0.06	0.17
62 ft	115 mph	Tangent	0.70	0.26	0.24	0.20	0.32	0.38	0.08	0.06	0.12
62 ft	120 mph	3 in	0.52	0.40	0.42	0.23	0.29	0.37	0.05	0.06	0.18
62 ft	120 mph	4 in	0.49	0.43	0.45	0.25	0.28	0.36	0.05	0.06	0.17
62 ft	120 mph	5 in	0.45	0.45	0.47	0.27	0.27	0.37	0.05	0.06	0.17
62 ft	120 mph	Tangent	0.69	0.27	0.24	0.15	0.33	0.36	0.06	0.06	0.15
62 ft	125 mph	3 in	0.49	0.43	0.44	0.25	0.30	0.36	0.05	0.06	0.17
62 ft	125 mph	4 in	0.45	0.45	0.47	0.27	0.29	0.35	0.05	0.06	0.17
62 ft	125 mph	5 in	0.41	0.48	0.49	0.29	0.28	0.35	0.05	0.06	0.17
62 ft	125 mph	Tangent	0.68	0.30	0.27	0.23	0.33	0.35	0.07	0.06	0.13
124 ft	115 mph	3 in	0.42	0.43	0.40	0.29	0.59	0.46	0.12	0.11	0.17
124 ft	115 mph	4 in	0.39	0.44	0.43	0.30	0.59	0.46	0.12	0.11	0.17
124 ft	115 mph	5 in	0.35	0.45	0.45	0.31	0.59	0.45	0.12	0.11	0.17
124 ft	115 mph	Tangent	0.55	0.32	0.28	0.21	0.67	0.49	0.14	0.12	0.14
124 ft	120 mph	3 in	0.42	0.43	0.43	0.29	0.63	0.54	0.12	0.13	0.17
124 ft	120 mph	4 in	0.37	0.45	0.45	0.30	0.64	0.54	0.13	0.13	0.17
124 ft	120 mph	5 in	0.34	0.46	0.46	0.31	0.64	0.53	0.12	0.12	0.17
124 ft	120 mph	Tangent	0.55	0.30	0.26	0.20	0.69	0.57	0.14	0.14	0.13
124 ft	125 mph	3 in	0.41	0.43	0.45	0.29	0.67	0.63	0.13	0.14	0.17
124 ft	125 mph	4 in	0.37	0.46	0.46	0.31	0.67	0.63	0.13	0.14	0.17
124 ft	125 mph	5 in	0.34	0.47	0.48	0.32	0.67	0.62	0.13	0.14	0.17
124 ft	125 mph	Tangent	0.57	0.33	0.29	0.23	0.70	0.66	0.14	0.15	0.16

Table 24. Journal Spring, Bi-Level Car, 56.5-inch Gage MCAT Results

Journal Spring, Bi-Level Car, 56.5" Gage											
Wavelength	Speed	Cant Deficiency	Min Wheel Vertical Load Ratio (0.15)	Maximum Wheel L/V Ratio (1.13)	Maximum Net Axle L/V Ratio	Maximum Truck Side L/V Ratio (0.6)	Maximum Carbody Lateral Peak to Peak Accel (0.65)	Maximum Carbody Vertical Peak to Peak Accel (1.0)	Carbody Lateral (sustained Oscillatory) (0.10)	Carbody Vertical (sustained Oscillatory) (0.25)	Maximum Truck Lateral Accel (0.3)
31 ft	115 mph	3 in	0.61	0.25	0.28	0.15	0.19	0.18	0.04	0.03	0.19
31 ft	115 mph	4 in	0.56	0.27	0.30	0.19	0.20	0.18	0.05	0.03	0.19
31 ft	115 mph	5 in	0.50	0.30	0.34	0.20	0.21	0.18	0.05	0.03	0.19
31 ft	115 mph	Tangent	0.72	0.20	0.18	0.14	0.36	0.18	0.11	0.03	0.14
31 ft	120 mph	3 in	0.59	0.27	0.30	0.17	0.18	0.18	0.04	0.03	0.20
31 ft	120 mph	4 in	0.53	0.31	0.34	0.19	0.19	0.18	0.05	0.03	0.19
31 ft	120 mph	5 in	0.48	0.32	0.35	0.21	0.20	0.18	0.05	0.03	0.19
31 ft	120 mph	Tangent	0.68	0.15	0.16	0.12	0.32	0.18	0.10	0.03	0.16
31 ft	125 mph	3 in	0.58	0.28	0.31	0.18	0.18	0.17	0.04	0.03	0.20
31 ft	125 mph	4 in	0.53	0.30	0.33	0.19	0.18	0.18	0.04	0.03	0.20
31 ft	125 mph	5 in	0.48	0.32	0.36	0.21	0.19	0.17	0.05	0.03	0.20
31 ft	125 mph	Tangent	0.68	0.17	0.17	0.13	0.28	0.18	0.10	0.03	0.17
62 ft	115 mph	3 in	0.60	0.27	0.30	0.17	0.26	0.23	0.06	0.04	0.19
62 ft	115 mph	4 in	0.55	0.31	0.33	0.19	0.25	0.23	0.06	0.04	0.19
62 ft	115 mph	5 in	0.49	0.33	0.35	0.20	0.24	0.24	0.06	0.04	0.18
62 ft	115 mph	Tangent	0.78	0.17	0.16	0.11	0.35	0.22	0.11	0.05	0.09
62 ft	120 mph	3 in	0.59	0.28	0.30	0.17	0.24	0.22	0.05	0.04	0.20
62 ft	120 mph	4 in	0.53	0.32	0.34	0.19	0.24	0.22	0.06	0.04	0.20
62 ft	120 mph	5 in	0.47	0.34	0.37	0.21	0.27	0.23	0.07	0.04	0.20
62 ft	120 mph	Tangent	0.75	0.26	0.24	0.21	0.43	0.22	0.13	0.04	0.13
62 ft	125 mph	3 in	0.59	0.28	0.31	0.18	0.24	0.22	0.06	0.04	0.20
62 ft	125 mph	4 in	0.54	0.30	0.33	0.19	0.24	0.22	0.06	0.04	0.20
62 ft	125 mph	5 in	0.48	0.32	0.36	0.20	0.24	0.22	0.06	0.04	0.20
62 ft	125 mph	Tangent	0.76	0.20	0.18	0.12	0.38	0.22	0.11	0.04	0.11
124 ft	115 mph	3 in	0.44	0.38	0.34	0.27	0.64	0.63	0.16	0.15	0.19
124 ft	115 mph	4 in	0.37	0.41	0.36	0.29	0.66	0.62	0.16	0.15	0.19
124 ft	115 mph	5 in	0.31	0.41	0.38	0.31	0.64	0.62	0.16	0.14	0.19
124 ft	115 mph	Tangent	0.56	0.28	0.27	0.22	0.71	0.69	0.18	0.16	0.11
124 ft	120 mph	3 in	0.45	0.39	0.34	0.28	0.69	0.68	0.17	0.16	0.20
124 ft	120 mph	4 in	0.41	0.41	0.36	0.28	0.66	0.66	0.16	0.15	0.20
124 ft	120 mph	5 in	0.36	0.43	0.38	0.32	0.66	0.65	0.17	0.15	0.20
124 ft	120 mph	Tangent	0.61	0.32	0.29	0.23	0.72	0.72	0.19	0.17	0.15
124 ft	125 mph	3 in	0.45	0.41	0.35	0.29	0.73	0.72	0.18	0.16	0.20
124 ft	125 mph	4 in	0.40	0.42	0.38	0.30	0.71	0.71	0.18	0.16	0.20
124 ft	125 mph	5 in	0.34	0.44	0.42	0.33	0.70	0.71	0.17	0.16	0.20
124 ft	125 mph	Tangent	0.62	0.31	0.30	0.25	0.80	0.76	0.22	0.17	0.13

Table 25. Journal Spring, Single-Level Car, 57.0-inch Gage MCAT Results

Journal Spring, Single-Level Car, 57.0" Gage											
Wavelength	Speed	Cant Deficiency	Min Wheel Vertical Load Ratio (0.15)	Maximum Wheel L/V Ratio (1.13)	Maximum Net Axle L/V Ratio	Maximum Truck Side L/V Ratio (0.6)	Maximum Carbody Lateral Peak to Peak Accel (0.65)	Maximum Carbody Vertical Peak to Peak Accel (1.0)	Carbody Lateral (sustained Oscillatory) (0.10)	Carbody Vertical (sustained Oscillatory) (0.25)	Maximum Truck Lateral Accel (0.3)
31 ft	115 mph	3 in	0.54	0.38	0.41	0.23	0.30	0.22	0.05	0.03	0.17
31 ft	115 mph	4 in	0.50	0.41	0.43	0.24	0.32	0.22	0.06	0.03	0.17
31 ft	115 mph	5 in	0.48	0.41	0.44	0.26	0.32	0.22	0.06	0.04	0.16
31 ft	120 mph	3 in	0.34	0.48	0.51	0.33	0.36	0.22	0.12	0.03	0.17
31 ft	120 mph	4 in	0.48	0.41	0.45	0.26	0.31	0.22	0.06	0.03	0.18
31 ft	120 mph	5 in	0.46	0.43	0.47	0.28	0.32	0.23	0.06	0.03	0.17
31 ft	125 mph	3 in	0.49	0.41	0.45	0.26	0.33	0.23	0.06	0.04	0.19
31 ft	125 mph	4 in	0.45	0.44	0.47	0.28	0.32	0.23	0.06	0.04	0.18
31 ft	125 mph	5 in	0.43	0.45	0.49	0.30	0.32	0.23	0.06	0.04	0.18
62 ft	115 mph	3 in	0.54	0.38	0.40	0.22	0.31	0.37	0.06	0.06	0.17
62 ft	115 mph	4 in	0.52	0.39	0.42	0.23	0.30	0.37	0.06	0.06	0.17
62 ft	115 mph	5 in	0.49	0.41	0.44	0.24	0.30	0.37	0.06	0.06	0.16
62 ft	120 mph	3 in	0.52	0.40	0.41	0.23	0.33	0.36	0.06	0.06	0.17
62 ft	120 mph	4 in	0.49	0.41	0.44	0.24	0.32	0.37	0.06	0.06	0.17
62 ft	120 mph	5 in	0.46	0.44	0.46	0.26	0.30	0.36	0.06	0.06	0.17
62 ft	125 mph	3 in	0.49	0.43	0.44	0.25	0.34	0.35	0.06	0.06	0.17
62 ft	125 mph	4 in	0.46	0.45	0.47	0.26	0.34	0.36	0.06	0.06	0.17
62 ft	125 mph	5 in	0.42	0.47	0.49	0.28	0.33	0.35	0.06	0.06	0.16
124 ft	115 mph	3 in	0.45	0.43	0.39	0.28	0.68	0.46	0.14	0.11	0.17
124 ft	115 mph	4 in	0.39	0.44	0.44	0.30	0.68	0.45	0.14	0.11	0.17
124 ft	115 mph	5 in	0.35	0.46	0.45	0.31	0.65	0.45	0.13	0.11	0.17
124 ft	120 mph	3 in	0.45	0.42	0.42	0.28	0.74	0.54	0.15	0.13	0.18
124 ft	120 mph	4 in	0.39	0.45	0.45	0.30	0.73	0.54	0.15	0.13	0.18
124 ft	120 mph	5 in	0.34	0.47	0.47	0.32	0.72	0.54	0.15	0.13	0.18
124 ft	125 mph	3 in	0.45	0.42	0.42	0.28	0.78	0.63	0.16	0.14	0.20
124 ft	125 mph	4 in	0.42	0.46	0.44	0.31	0.78	0.63	0.16	0.14	0.19
124 ft	125 mph	5 in	0.34	0.48	0.47	0.32	0.76	0.62	0.15	0.14	0.19

Table 26. Journal Spring, Bi-Level Car, 57.0-inch Gage MCAT Results

Journal Spring, Bi-Level Car, 57.0" Gage											
Wavelength	Speed	Cant Deficiency	Min Wheel Vertical Load Ratio (0.15)	Maximum Wheel L/V Ratio (1.13)	Maximum Net Axle L/V Ratio	Maximum Truck Side L/V Ratio (0.6)	Maximum Carbody Lateral Peak to Peak Accel (0.65)	Maximum Carbody Vertical Peak to Peak Accel (1.0)	Carbody Lateral (sustained Oscillatory) (0.10)	Carbody Vertical (sustained Oscillatory) (0.25)	Maximum Truck Lateral Accel (0.3)
31 ft	115 mph	3 in	0.61	0.25	0.28	0.15	0.20	0.18	0.05	0.03	0.18
31 ft	115 mph	4 in	0.55	0.28	0.31	0.17	0.22	0.18	0.06	0.03	0.19
31 ft	115 mph	5 in	0.50	0.31	0.34	0.19	0.23	0.18	0.06	0.03	0.19
31 ft	120 mph	3 in	0.30	0.37	0.40	0.25	0.20	0.18	0.05	0.03	0.18
31 ft	120 mph	4 in	0.54	0.30	0.33	0.19	0.20	0.18	0.05	0.03	0.19
31 ft	120 mph	5 in	0.48	0.33	0.36	0.21	0.22	0.18	0.06	0.03	0.18
31 ft	125 mph	3 in	0.57	0.28	0.30	0.17	0.22	0.18	0.06	0.03	0.19
31 ft	125 mph	4 in	0.52	0.30	0.33	0.19	0.21	0.17	0.05	0.03	0.19
31 ft	125 mph	5 in	0.47	0.33	0.36	0.21	0.24	0.18	0.06	0.03	0.19
62 ft	115 mph	3 in	0.60	0.27	0.30	0.16	0.22	0.23	0.06	0.04	0.18
62 ft	115 mph	4 in	0.55	0.30	0.33	0.18	0.23	0.23	0.06	0.04	0.19
62 ft	115 mph	5 in	0.49	0.33	0.36	0.20	0.24	0.24	0.06	0.04	0.19
62 ft	120 mph	3 in	0.59	0.27	0.30	0.16	0.22	0.22	0.06	0.04	0.19
62 ft	120 mph	4 in	0.54	0.30	0.33	0.19	0.23	0.22	0.06	0.04	0.19
62 ft	120 mph	5 in	0.48	0.33	0.36	0.20	0.25	0.23	0.07	0.04	0.19
62 ft	125 mph	3 in	0.58	0.27	0.30	0.16	0.24	0.22	0.07	0.04	0.19
62 ft	125 mph	4 in	0.54	0.30	0.32	0.18	0.25	0.22	0.07	0.04	0.19
62 ft	125 mph	5 in	0.48	0.32	0.35	0.20	0.26	0.22	0.07	0.04	0.20
124 ft	115 mph	3 in	0.44	0.46	0.38	0.33	0.86	0.63	0.21	0.15	0.18
124 ft	115 mph	4 in	0.39	0.48	0.39	0.37	0.83	0.62	0.21	0.14	0.19
124 ft	115 mph	5 in	0.34	0.48	0.39	0.39	0.80	0.61	0.19	0.14	0.18
124 ft	120 mph	3 in	0.45	0.47	0.39	0.35	0.92	0.68	0.23	0.16	0.19
124 ft	120 mph	4 in	0.40	0.52	0.41	0.38	0.89	0.67	0.22	0.15	0.20
124 ft	120 mph	5 in	0.36	0.49	0.40	0.40	0.82	0.66	0.20	0.15	0.19
124 ft	125 mph	3 in	0.39	0.49	0.41	0.36	0.97	0.72	0.25	0.16	0.20
124 ft	125 mph	4 in	0.36	0.56	0.43	0.40	0.95	0.71	0.24	0.16	0.21
124 ft	125 mph	5 in	0.30	0.53	0.42	0.43	0.91	0.70	0.23	0.16	0.21

Radial Arm MCAT Results

Table 27 through Table 30 show all MCAT results for the radial arm suspension truck. The most important observations of these results are that none of the force output (L/V ratios) nor truck lateral accelerations show any exceedances. All exceedances of the radial arm suspension trucks are of the carbody lateral acceleration output, but are far fewer than for other truck suspensions.

Table 27. Radial Arm, Single-Level Car, 56.5-inch Gage MCAT Results

Radial Arm, Single-Level Car, 56.5" Gage											
Wavelength	Speed	Cant Deficiency	Min Wheel Vertical Load Ratio (0.15)	Maximum Wheel L/V Ratio (1.13)	Maximum Net Axle L/V Ratio	Maximum Truck Side L/V Ratio (0.6)	Maximum Carbody Lateral Peak to Peak Accel (0.65)	Maximum Carbody Vertical Peak to Peak Accel (1.0)	Carbody Lateral (sustained Oscillatory) (0.10)	Carbody Vertical (sustained Oscillatory) (0.25)	Maximum Truck Lateral Accel (0.3)
31 ft	115 mph	3 in	0.52	0.44	0.50	0.33	0.31	0.35	0.05	0.06	0.21
31 ft	115 mph	4 in	0.49	0.46	0.52	0.34	0.30	0.35	0.05	0.06	0.21
31 ft	115 mph	5 in	0.46	0.47	0.53	0.34	0.30	0.35	0.05	0.06	0.20
31 ft	115 mph	Tangent	0.63	0.24	0.28	0.20	0.21	0.35	0.06	0.06	0.16
31 ft	120 mph	3 in	0.34	0.55	0.60	0.42	0.31	0.36	0.08	0.06	0.21
31 ft	120 mph	4 in	0.46	0.49	0.55	0.37	0.32	0.36	0.05	0.06	0.22
31 ft	120 mph	5 in	0.42	0.50	0.57	0.38	0.32	0.36	0.05	0.06	0.22
31 ft	120 mph	Tangent	0.64	0.37	0.43	0.27	0.27	0.36	0.07	0.06	0.21
31 ft	125 mph	3 in	0.50	0.48	0.56	0.37	0.33	0.35	0.05	0.07	0.24
31 ft	125 mph	4 in	0.43	0.50	0.58	0.39	0.33	0.36	0.05	0.07	0.24
31 ft	125 mph	5 in	0.40	0.54	0.60	0.41	0.34	0.36	0.05	0.07	0.24
31 ft	125 mph	Tangent	0.59	0.47	0.53	0.36	0.34	0.35	0.07	0.07	0.24
62 ft	115 mph	3 in	0.62	0.44	0.47	0.28	0.35	0.38	0.06	0.06	0.21
62 ft	115 mph	4 in	0.60	0.45	0.48	0.29	0.34	0.38	0.06	0.06	0.21
62 ft	115 mph	5 in	0.57	0.47	0.51	0.30	0.34	0.38	0.06	0.06	0.21
62 ft	115 mph	Tangent	0.76	0.33	0.29	0.25	0.36	0.38	0.08	0.06	0.14
62 ft	120 mph	3 in	0.60	0.46	0.47	0.30	0.36	0.37	0.06	0.06	0.21
62 ft	120 mph	4 in	0.58	0.47	0.51	0.31	0.35	0.37	0.06	0.06	0.21
62 ft	120 mph	5 in	0.53	0.48	0.52	0.32	0.34	0.37	0.06	0.06	0.21
62 ft	120 mph	Tangent	0.76	0.40	0.29	0.27	0.38	0.37	0.09	0.06	0.18
62 ft	125 mph	3 in	0.56	0.48	0.49	0.31	0.35	0.36	0.05	0.07	0.20
62 ft	125 mph	4 in	0.51	0.50	0.52	0.32	0.35	0.36	0.06	0.07	0.20
62 ft	125 mph	5 in	0.47	0.52	0.54	0.33	0.34	0.36	0.06	0.07	0.20
62 ft	125 mph	Tangent	0.73	0.36	0.25	0.23	0.30	0.36	0.07	0.07	0.20
124 ft	115 mph	3 in	0.48	0.44	0.46	0.29	0.69	0.65	0.12	0.16	0.21
124 ft	115 mph	4 in	0.45	0.45	0.48	0.30	0.65	0.65	0.12	0.16	0.21
124 ft	115 mph	5 in	0.41	0.47	0.50	0.32	0.65	0.65	0.12	0.16	0.21
124 ft	115 mph	Tangent	0.62	0.44	0.33	0.28	0.71	0.66	0.14	0.16	0.16
124 ft	120 mph	3 in	0.47	0.46	0.49	0.29	0.69	0.79	0.13	0.19	0.21
124 ft	120 mph	4 in	0.43	0.49	0.52	0.31	0.69	0.79	0.13	0.19	0.21
124 ft	120 mph	5 in	0.39	0.52	0.54	0.33	0.70	0.80	0.13	0.19	0.20
124 ft	120 mph	Tangent	0.59	0.42	0.30	0.23	0.71	0.79	0.14	0.19	0.16
124 ft	125 mph	3 in	0.47	0.49	0.51	0.30	0.68	0.92	0.13	0.21	0.20
124 ft	125 mph	4 in	0.42	0.51	0.53	0.32	0.70	0.93	0.14	0.21	0.20
124 ft	125 mph	5 in	0.39	0.53	0.55	0.32	0.73	0.93	0.14	0.21	0.20
124 ft	125 mph	Tangent	0.62	0.42	0.30	0.24	0.76	0.92	0.15	0.21	0.17

Table 28. Radial Arm, Bi-Level Car, 56.5-inch Gage MCAT Results

Radial Arm, Bi-Level Car, 56.5" Gage											
Wavelength	Speed	Cant Deficiency	Min Wheel Vertical Load Ratio (0.15)	Maximum Wheel L/V Ratio (1.13)	Maximum Net Axle L/V Ratio	Maximum Truck Side L/V Ratio (0.6)	Maximum Carbody Lateral Peak to Peak Accel (0.65)	Maximum Carbody Vertical Peak to Peak Accel (1.0)	Carbody Lateral (sustained Oscillatory) (0.10)	Carbody Vertical (sustained Oscillatory) (0.25)	Maximum Truck Lateral Accel (0.3)
31 ft	115 mph	3 in	0.65	0.28	0.33	0.20	0.22	0.24	0.05	0.05	0.23
31 ft	115 mph	4 in	0.58	0.31	0.35	0.22	0.21	0.24	0.05	0.05	0.23
31 ft	115 mph	5 in	0.53	0.35	0.38	0.24	0.21	0.24	0.06	0.05	0.23
31 ft	115 mph	Tangent	0.74	0.19	0.20	0.16	0.32	0.24	0.11	0.05	0.18
31 ft	120 mph	3 in	0.31	0.48	0.50	0.34	0.43	0.25	0.12	0.05	0.24
31 ft	120 mph	4 in	0.53	0.33	0.37	0.24	0.23	0.25	0.05	0.05	0.24
31 ft	120 mph	5 in	0.48	0.35	0.39	0.27	0.23	0.26	0.06	0.05	0.24
31 ft	120 mph	Tangent	0.66	0.25	0.27	0.18	0.39	0.26	0.11	0.05	0.21
31 ft	125 mph	3 in	0.62	0.33	0.37	0.24	0.23	0.26	0.05	0.05	0.24
31 ft	125 mph	4 in	0.55	0.35	0.39	0.26	0.23	0.27	0.05	0.05	0.24
31 ft	125 mph	5 in	0.47	0.37	0.41	0.28	0.23	0.26	0.05	0.05	0.24
31 ft	125 mph	Tangent	0.69	0.26	0.28	0.19	0.31	0.26	0.11	0.05	0.22
62 ft	115 mph	3 in	0.63	0.30	0.34	0.21	0.28	0.23	0.07	0.05	0.23
62 ft	115 mph	4 in	0.56	0.34	0.37	0.23	0.28	0.23	0.07	0.05	0.23
62 ft	115 mph	5 in	0.50	0.37	0.40	0.25	0.28	0.23	0.08	0.05	0.23
62 ft	115 mph	Tangent	0.79	0.16	0.15	0.11	0.38	0.23	0.12	0.05	0.08
62 ft	120 mph	3 in	0.65	0.31	0.35	0.21	0.27	0.24	0.06	0.05	0.24
62 ft	120 mph	4 in	0.58	0.35	0.37	0.23	0.27	0.24	0.06	0.05	0.24
62 ft	120 mph	5 in	0.51	0.36	0.40	0.24	0.27	0.24	0.06	0.05	0.23
62 ft	120 mph	Tangent	0.78	0.45	0.28	0.29	0.51	0.24	0.13	0.05	0.17
62 ft	125 mph	3 in	0.66	0.32	0.35	0.21	0.27	0.25	0.06	0.05	0.24
62 ft	125 mph	4 in	0.61	0.34	0.37	0.22	0.27	0.25	0.07	0.05	0.24
62 ft	125 mph	5 in	0.55	0.37	0.40	0.24	0.27	0.25	0.07	0.05	0.24
62 ft	125 mph	Tangent	0.79	0.30	0.24	0.21	0.46	0.25	0.13	0.05	0.13
124 ft	115 mph	3 in	0.38	0.38	0.37	0.26	0.68	0.88	0.17	0.21	0.23
124 ft	115 mph	4 in	0.33	0.43	0.41	0.29	0.69	0.88	0.18	0.21	0.23
124 ft	115 mph	5 in	0.29	0.44	0.43	0.34	0.70	0.88	0.19	0.21	0.23
124 ft	115 mph	Tangent	0.56	0.28	0.27	0.22	0.81	0.87	0.21	0.21	0.11
124 ft	120 mph	3 in	0.40	0.42	0.34	0.29	0.74	0.90	0.18	0.21	0.25
124 ft	120 mph	4 in	0.32	0.43	0.37	0.30	0.73	0.90	0.18	0.21	0.25
124 ft	120 mph	5 in	0.23	0.43	0.40	0.31	0.70	0.90	0.18	0.21	0.25
124 ft	120 mph	Tangent	0.57	0.30	0.27	0.24	0.87	0.89	0.24	0.21	0.14
124 ft	125 mph	3 in	0.44	0.41	0.34	0.29	0.77	0.89	0.19	0.21	0.25
124 ft	125 mph	4 in	0.40	0.44	0.36	0.30	0.76	0.90	0.19	0.21	0.25
124 ft	125 mph	5 in	0.34	0.46	0.38	0.33	0.77	0.91	0.20	0.21	0.24
124 ft	125 mph	Tangent	0.58	0.43	0.27	0.26	0.75	0.88	0.18	0.21	0.16

Table 29. Radial Arm, Single-Level Car, 57.0-inch Gage MCAT Results

Radial Arm, Single-Level Car, 57.0" Gage											
Wavelength	Speed	Cant Deficiency	Min Wheel Vertical Load Ratio (0.15)	Maximum Wheel L/V Ratio (1.13)	Maximum Net Axle L/V Ratio	Maximum Truck Side L/V Ratio (0.6)	Maximum Carbody Lateral Peak to Peak Accel (0.65)	Maximum Carbody Vertical Peak to Peak Accel (1.0)	Carbody Lateral (sustained Oscillatory) (0.10)	Carbody Vertical (sustained Oscillatory) (0.25)	Maximum Truck Lateral Accel (0.3)
31 ft	115 mph	3 in	0.54	0.43	0.48	0.31	0.36	0.35	0.07	0.06	0.20
31 ft	115 mph	4 in	0.49	0.46	0.52	0.34	0.38	0.35	0.08	0.06	0.21
31 ft	115 mph	5 in	0.45	0.47	0.53	0.34	0.36	0.35	0.07	0.06	0.20
31 ft	120 mph	3 in	0.21	0.76	0.76	0.61	0.67	0.36	0.19	0.07	0.30
31 ft	120 mph	4 in	0.49	0.47	0.54	0.36	0.40	0.36	0.08	0.06	0.22
31 ft	120 mph	5 in	0.41	0.49	0.55	0.36	0.39	0.36	0.08	0.06	0.22
31 ft	125 mph	3 in	0.51	0.47	0.54	0.36	0.41	0.35	0.10	0.07	0.22
31 ft	125 mph	4 in	0.50	0.49	0.56	0.37	0.41	0.36	0.09	0.07	0.23
31 ft	125 mph	5 in	0.41	0.51	0.57	0.38	0.41	0.36	0.09	0.07	0.23
62 ft	115 mph	3 in	0.62	0.43	0.46	0.27	0.40	0.38	0.07	0.06	0.20
62 ft	115 mph	4 in	0.59	0.45	0.48	0.28	0.38	0.38	0.07	0.06	0.20
62 ft	115 mph	5 in	0.56	0.46	0.51	0.30	0.36	0.38	0.07	0.06	0.20
62 ft	120 mph	3 in	0.62	0.44	0.47	0.27	0.42	0.37	0.09	0.06	0.20
62 ft	120 mph	4 in	0.59	0.45	0.49	0.28	0.41	0.37	0.08	0.06	0.20
62 ft	120 mph	5 in	0.54	0.46	0.50	0.29	0.39	0.37	0.07	0.06	0.20
62 ft	125 mph	3 in	0.57	0.46	0.49	0.28	0.41	0.36	0.10	0.07	0.20
62 ft	125 mph	4 in	0.54	0.48	0.50	0.30	0.43	0.36	0.09	0.07	0.19
62 ft	125 mph	5 in	0.51	0.48	0.51	0.30	0.41	0.36	0.08	0.07	0.19
124 ft	115 mph	3 in	0.49	0.52	0.45	0.29	0.70	0.66	0.15	0.16	0.20
124 ft	115 mph	4 in	0.46	0.54	0.47	0.31	0.70	0.66	0.15	0.16	0.20
124 ft	115 mph	5 in	0.42	0.54	0.50	0.33	0.67	0.65	0.15	0.16	0.20
124 ft	120 mph	3 in	0.48	0.50	0.49	0.30	0.73	0.79	0.16	0.19	0.21
124 ft	120 mph	4 in	0.45	0.51	0.49	0.30	0.73	0.79	0.16	0.19	0.20
124 ft	120 mph	5 in	0.40	0.52	0.51	0.32	0.73	0.79	0.16	0.19	0.21
124 ft	125 mph	3 in	0.51	0.49	0.49	0.33	0.81	0.92	0.19	0.21	0.23
124 ft	125 mph	4 in	0.48	0.50	0.50	0.33	0.81	0.92	0.18	0.21	0.23
124 ft	125 mph	5 in	0.44	0.51	0.53	0.34	0.80	0.92	0.17	0.21	0.22

Table 30. Radial Arm, Bi-Level Car, 57.0-inch Gage MCAT Results

Radial Arm, Bi-Level Car, 57.0" Gage											
Wavelength	Speed	Cant Deficiency	Min Wheel Vertical Load Ratio (0.15)	Maximum Wheel L/V Ratio (1.13)	Maximum Net Axle L/V Ratio	Maximum Truck Side L/V Ratio (0.6)	Maximum Carbody Lateral Peak to Peak Accel (0.65)	Maximum Carbody Vertical Peak to Peak Accel (1.0)	Carbody Lateral (sustained Oscillatory) (0.10)	Carbody Vertical (sustained Oscillatory) (0.25)	Maximum Truck Lateral Accel (0.3)
31 ft	115 mph	3 in	0.63	0.29	0.32	0.20	0.26	0.24	0.06	0.05	0.23
31 ft	115 mph	4 in	0.59	0.30	0.35	0.22	0.24	0.24	0.06	0.05	0.23
31 ft	115 mph	5 in	0.52	0.33	0.38	0.23	0.22	0.24	0.06	0.04	0.23
31 ft	120 mph	3 in	0.26	0.55	0.47	0.43	0.65	0.25	0.21	0.05	0.28
31 ft	120 mph	4 in	0.54	0.32	0.37	0.23	0.27	0.25	0.08	0.05	0.24
31 ft	120 mph	5 in	0.49	0.34	0.39	0.25	0.27	0.25	0.08	0.05	0.24
31 ft	125 mph	3 in	0.61	0.32	0.36	0.22	0.45	0.27	0.14	0.05	0.23
31 ft	125 mph	4 in	0.55	0.34	0.38	0.24	0.39	0.26	0.11	0.05	0.23
31 ft	125 mph	5 in	0.47	0.36	0.40	0.26	0.33	0.26	0.09	0.05	0.24
62 ft	115 mph	3 in	0.62	0.31	0.35	0.21	0.29	0.23	0.08	0.05	0.23
62 ft	115 mph	4 in	0.56	0.33	0.37	0.23	0.28	0.23	0.07	0.05	0.23
62 ft	115 mph	5 in	0.50	0.36	0.40	0.25	0.27	0.23	0.07	0.05	0.23
62 ft	120 mph	3 in	0.61	0.30	0.34	0.21	0.35	0.24	0.10	0.05	0.24
62 ft	120 mph	4 in	0.56	0.32	0.37	0.23	0.31	0.24	0.09	0.05	0.24
62 ft	120 mph	5 in	0.50	0.35	0.40	0.24	0.28	0.24	0.08	0.05	0.24
62 ft	125 mph	3 in	0.63	0.36	0.38	0.24	0.47	0.25	0.13	0.05	0.24
62 ft	125 mph	4 in	0.57	0.32	0.36	0.22	0.46	0.25	0.13	0.05	0.24
62 ft	125 mph	5 in	0.53	0.35	0.39	0.23	0.41	0.25	0.11	0.05	0.24
124 ft	115 mph	3 in	0.36	0.50	0.39	0.33	0.94	0.87	0.25	0.21	0.23
124 ft	115 mph	4 in	0.31	0.51	0.40	0.34	0.91	0.87	0.24	0.21	0.23
124 ft	115 mph	5 in	0.27	0.51	0.41	0.38	0.84	0.87	0.23	0.21	0.23
124 ft	120 mph	3 in	0.30	0.50	0.40	0.35	1.03	0.90	0.27	0.21	0.24
124 ft	120 mph	4 in	0.26	0.52	0.41	0.37	1.03	0.91	0.27	0.21	0.24
124 ft	120 mph	5 in	0.19	0.55	0.44	0.40	0.99	0.91	0.25	0.21	0.24
124 ft	125 mph	3 in	0.41	0.51	0.47	0.36	1.07	0.89	0.29	0.21	0.26
124 ft	125 mph	4 in	0.36	0.53	0.44	0.38	1.06	0.90	0.28	0.21	0.25
124 ft	125 mph	5 in	0.29	0.58	0.46	0.44	1.02	0.91	0.26	0.21	0.26

Rubber Chevron MCAT Results

Table 31 through Table 34 show all MCAT results for the rubber chevron trucks. There is a notable difference of the 56.5-inch results as compared to the 57.0-inch results. The tighter gage results yield many more exceedances of the L/V outputs as well as the lateral truck acceleration results.

Table 31. Rubber Chevron, Single-Level Car, 56.5-inch Gage MCAT Results

Rubber Chevron, Single-Level Car, 56.5" Gage											
Wavelength	Speed	Cant Deficiency	Min Wheel Vertical Load Ratio (0.15)	Maximum Wheel L/V Ratio (1.13)	Maximum Net Axle L/V Ratio	Maximum Truck Side L/V Ratio (0.6)	Maximum Carbody Lateral Peak to Peak Accel (0.65)	Maximum Carbody Vertical Peak to Peak Accel (1.0)	Carbody Lateral (sustained Oscillatory) (0.10)	Carbody Vertical (sustained Oscillatory) (0.25)	Maximum Truck Lateral Accel (0.3)
31 ft	115 mph	3 in	0.47	0.99	0.81	0.75	1.66	0.38	0.47	0.06	0.47
31 ft	115 mph	4 in	0.64	0.67	0.53	0.48	0.77	0.38	0.18	0.06	0.19
31 ft	115 mph	5 in	0.62	0.70	0.55	0.51	0.78	0.38	0.15	0.06	0.18
31 ft	115 mph	Tangent	0.63	0.27	0.26	0.21	0.64	0.38	0.09	0.06	0.15
31 ft	120 mph	3 in	0.43	1.05	0.81	0.75	1.63	0.41	0.47	0.07	0.47
31 ft	120 mph	4 in	0.40	0.96	0.75	0.69	1.39	0.42	0.45	0.07	0.41
31 ft	120 mph	5 in	0.39	0.95	0.77	0.70	1.38	0.42	0.41	0.07	0.37
31 ft	120 mph	Tangent	0.60	0.78	0.61	0.57	1.34	0.40	0.48	0.06	0.47
31 ft	125 mph	3 in	0.34	1.07	0.82	0.73	1.71	0.40	0.54	0.07	0.52
31 ft	125 mph	4 in	0.34	1.12	1.00	0.84	1.67	0.40	0.51	0.07	0.52
31 ft	125 mph	5 in	0.34	1.03	0.95	0.81	1.59	0.41	0.49	0.07	0.48
31 ft	125 mph	Tangent	0.48	0.92	0.76	0.71	1.72	0.40	0.52	0.07	0.56
62 ft	115 mph	3 in	0.40	1.18	1.01	0.97	1.85	0.43	0.47	0.07	0.43
62 ft	115 mph	4 in	0.39	1.02	0.87	0.84	1.50	0.44	0.43	0.07	0.39
62 ft	115 mph	5 in	0.38	1.01	0.82	0.79	1.31	0.45	0.35	0.07	0.35
62 ft	115 mph	Tangent	0.50	1.05	0.83	0.85	1.66	0.44	0.49	0.07	0.54
62 ft	120 mph	3 in	0.49	1.02	0.84	0.78	1.60	0.44	0.48	0.07	0.50
62 ft	120 mph	4 in	0.46	1.01	0.83	0.79	1.50	0.44	0.48	0.07	0.49
62 ft	120 mph	5 in	0.42	1.13	0.98	0.93	1.68	0.41	0.42	0.07	0.46
62 ft	120 mph	Tangent	0.42	1.18	0.96	0.91	1.89	0.43	0.53	0.07	0.61
62 ft	125 mph	3 in	0.35	1.22	1.04	0.97	1.88	0.44	0.54	0.07	0.54
62 ft	125 mph	4 in	0.33	1.29	1.12	1.08	2.04	0.42	0.48	0.07	0.50
62 ft	125 mph	5 in	0.30	1.14	0.96	0.93	1.60	0.41	0.44	0.07	0.42
62 ft	125 mph	Tangent	0.45	1.17	0.90	0.92	1.88	0.42	0.54	0.07	0.66
124 ft	115 mph	3 in	0.37	0.46	0.40	0.34	0.68	0.55	0.14	0.13	0.18
124 ft	115 mph	4 in	0.36	0.47	0.40	0.34	0.61	0.55	0.11	0.13	0.18
124 ft	115 mph	5 in	0.34	0.47	0.41	0.35	0.59	0.56	0.13	0.13	0.17
124 ft	115 mph	Tangent	0.48	0.90	0.74	0.69	1.53	0.55	0.48	0.13	0.51
124 ft	120 mph	3 in	0.44	0.90	0.70	0.66	1.30	0.66	0.46	0.16	0.43
124 ft	120 mph	4 in	0.41	0.84	0.66	0.63	1.18	0.66	0.43	0.16	0.41
124 ft	120 mph	5 in	0.37	0.78	0.63	0.60	1.06	0.66	0.39	0.16	0.36
124 ft	120 mph	Tangent	0.36	1.00	0.82	0.77	1.72	0.66	0.52	0.16	0.60
124 ft	125 mph	3 in	0.35	0.97	0.82	0.76	1.54	0.78	0.49	0.18	0.46
124 ft	125 mph	4 in	0.31	0.93	0.80	0.76	1.47	0.78	0.46	0.18	0.40
124 ft	125 mph	5 in	0.29	0.86	0.77	0.74	1.36	0.78	0.42	0.18	0.36
124 ft	125 mph	Tangent	0.26	0.97	0.79	0.74	1.79	0.78	0.53	0.18	0.51

Table 32. Rubber Chevron, Bi-Level Car, 56.5-inch Gage MCAT Results

Rubber Chevron, Bi-Level Car, 56.5" Gage											
Wavelength	Speed	Cant Deficiency	Min Wheel Vertical Load Ratio (0.15)	Maximum Wheel L/V Ratio (1.13)	Maximum Net Axle L/V Ratio	Maximum Truck Side L/V Ratio (0.6)	Maximum Carbody Lateral Peak to Peak Accel (0.65)	Maximum Carbody Vertical Peak to Peak Accel (1.0)	Carbody Lateral (sustained Oscillatory) (0.10)	Carbody Vertical (sustained Oscillatory) (0.25)	Maximum Truck Lateral Accel (0.3)
31 ft	115 mph	3 in	0.64	0.31	0.31	0.25	0.64	0.32	0.12	0.05	0.16
31 ft	115 mph	4 in	0.57	0.33	0.34	0.26	0.65	0.32	0.12	0.05	0.17
31 ft	115 mph	5 in	0.51	0.35	0.35	0.28	0.64	0.32	0.12	0.05	0.18
31 ft	115 mph	Tangent	0.75	0.14	0.14	0.12	0.43	0.33	0.06	0.05	0.12
31 ft	120 mph	3 in	0.60	0.32	0.32	0.26	0.65	0.34	0.12	0.05	0.18
31 ft	120 mph	4 in	0.55	0.33	0.34	0.27	0.65	0.33	0.12	0.05	0.19
31 ft	120 mph	5 in	0.49	0.36	0.36	0.29	0.64	0.33	0.12	0.05	0.19
31 ft	120 mph	Tangent	0.73	0.17	0.16	0.14	0.47	0.33	0.06	0.05	0.14
31 ft	125 mph	3 in	0.63	0.32	0.32	0.26	0.70	0.34	0.13	0.06	0.18
31 ft	125 mph	4 in	0.57	0.34	0.34	0.27	0.67	0.34	0.13	0.06	0.18
31 ft	125 mph	5 in	0.50	0.36	0.36	0.30	0.68	0.34	0.13	0.06	0.19
31 ft	125 mph	Tangent	0.72	0.18	0.17	0.15	0.51	0.34	0.07	0.06	0.16
62 ft	115 mph	3 in	0.44	0.78	0.64	0.62	1.34	0.31	0.34	0.05	0.28
62 ft	115 mph	4 in	0.44	0.78	0.64	0.63	1.25	0.30	0.28	0.05	0.25
62 ft	115 mph	5 in	0.41	0.72	0.60	0.59	1.13	0.30	0.24	0.05	0.21
62 ft	115 mph	Tangent	0.46	1.02	0.77	0.82	1.90	0.30	0.54	0.05	0.44
62 ft	120 mph	3 in	0.51	0.77	0.64	0.64	1.42	0.29	0.33	0.05	0.29
62 ft	120 mph	4 in	0.48	0.74	0.60	0.60	1.27	0.29	0.30	0.05	0.27
62 ft	120 mph	5 in	0.46	0.73	0.60	0.58	1.17	0.29	0.25	0.05	0.22
62 ft	120 mph	Tangent	0.54	0.97	0.74	0.78	1.97	0.29	0.63	0.05	0.55
62 ft	125 mph	3 in	0.44	0.75	0.61	0.61	1.39	0.29	0.40	0.05	0.29
62 ft	125 mph	4 in	0.43	0.73	0.62	0.61	1.31	0.28	0.32	0.05	0.26
62 ft	125 mph	5 in	0.39	0.69	0.59	0.59	1.17	0.29	0.24	0.05	0.21
62 ft	125 mph	Tangent	0.43	1.08	0.84	0.93	2.10	0.29	0.54	0.05	0.45
124 ft	115 mph	3 in	0.36	0.44	0.41	0.38	0.83	0.73	0.22	0.17	0.17
124 ft	115 mph	4 in	0.30	0.41	0.40	0.40	0.76	0.73	0.17	0.17	0.15
124 ft	115 mph	5 in	0.24	0.44	0.42	0.41	0.74	0.73	0.16	0.17	0.17
124 ft	115 mph	Tangent	0.44	0.76	0.63	0.64	1.59	0.74	0.54	0.17	0.40
124 ft	120 mph	3 in	0.28	0.70	0.63	0.58	1.44	0.82	0.41	0.19	0.31
124 ft	120 mph	4 in	0.26	0.62	0.59	0.52	1.19	0.82	0.31	0.19	0.26
124 ft	120 mph	5 in	0.25	0.55	0.52	0.45	0.89	0.82	0.21	0.19	0.20
124 ft	120 mph	Tangent	0.41	0.76	0.63	0.65	1.61	0.83	0.54	0.19	0.42
124 ft	125 mph	3 in	0.21	0.91	0.73	0.76	1.73	0.89	0.46	0.21	0.37
124 ft	125 mph	4 in	0.16	0.87	0.72	0.73	1.61	0.89	0.43	0.21	0.35
124 ft	125 mph	5 in	0.12	0.76	0.69	0.64	1.41	0.89	0.36	0.21	0.29
124 ft	125 mph	Tangent	0.25	1.18	0.84	0.97	2.20	0.90	0.58	0.21	0.53

Table 33. Rubber Chevron, Single-Level Car, 57.0-inch Gage MCAT Results

Rubber Chevron, Single-Level Car, 57.0" Gage											
Wavelength	Speed	Cant Deficiency	Min Wheel Vertical Load Ratio (0.15)	Maximum Wheel L/V Ratio (1.13)	Maximum Net Axle L/V Ratio	Maximum Truck Side L/V Ratio (0.6)	Maximum Carbody Lateral Peak to Peak Accel (0.65)	Maximum Carbody Vertical Peak to Peak Accel (1.0)	Carbody Lateral (sustained Oscillatory) (0.10)	Carbody Vertical (sustained Oscillatory) (0.25)	Maximum Truck Lateral Accel (0.3)
31 ft	115 mph	3 in	0.67	0.43	0.38	0.29	0.58	0.38	0.10	0.06	0.16
31 ft	115 mph	4 in	0.64	0.52	0.44	0.37	0.67	0.38	0.12	0.06	0.16
31 ft	115 mph	5 in	0.61	0.56	0.48	0.42	0.69	0.38	0.11	0.06	0.17
31 ft	120 mph	3 in	0.67	0.44	0.39	0.31	0.66	0.40	0.11	0.06	0.17
31 ft	120 mph	4 in	0.64	0.51	0.44	0.36	0.66	0.40	0.12	0.06	0.17
31 ft	120 mph	5 in	0.61	0.59	0.50	0.44	0.74	0.40	0.13	0.06	0.17
31 ft	125 mph	3 in	0.65	0.46	0.41	0.32	0.72	0.41	0.12	0.07	0.18
31 ft	125 mph	4 in	0.63	0.54	0.46	0.39	0.72	0.41	0.13	0.07	0.18
31 ft	125 mph	5 in	0.56	0.67	0.53	0.47	0.82	0.41	0.14	0.07	0.18
62 ft	115 mph	3 in	0.63	0.54	0.45	0.38	0.71	0.44	0.12	0.07	0.16
62 ft	115 mph	4 in	0.59	0.57	0.49	0.43	0.75	0.44	0.13	0.07	0.16
62 ft	115 mph	5 in	0.55	0.61	0.52	0.45	0.76	0.44	0.13	0.07	0.17
62 ft	120 mph	3 in	0.64	0.56	0.47	0.40	0.74	0.43	0.13	0.07	0.16
62 ft	120 mph	4 in	0.60	0.62	0.53	0.47	0.80	0.43	0.14	0.07	0.17
62 ft	120 mph	5 in	0.56	0.69	0.55	0.49	0.80	0.42	0.14	0.07	0.18
62 ft	125 mph	3 in	0.63	0.53	0.44	0.38	0.72	0.42	0.13	0.07	0.17
62 ft	125 mph	4 in	0.58	0.63	0.51	0.45	0.79	0.41	0.14	0.07	0.17
62 ft	125 mph	5 in	0.53	0.70	0.56	0.50	0.83	0.41	0.15	0.07	0.18
124 ft	115 mph	3 in	0.38	0.53	0.45	0.39	0.73	0.55	0.14	0.13	0.16
124 ft	115 mph	4 in	0.37	0.51	0.43	0.38	0.65	0.55	0.14	0.13	0.16
124 ft	115 mph	5 in	0.34	0.53	0.45	0.40	0.63	0.56	0.15	0.13	0.16
124 ft	120 mph	3 in	0.46	0.75	0.57	0.53	1.03	0.65	0.22	0.16	0.25
124 ft	120 mph	4 in	0.42	0.67	0.56	0.50	0.95	0.65	0.19	0.16	0.21
124 ft	120 mph	5 in	0.38	0.64	0.54	0.48	0.85	0.66	0.19	0.16	0.20
124 ft	125 mph	3 in	0.37	0.91	0.73	0.65	1.16	0.78	0.37	0.18	0.44
124 ft	125 mph	4 in	0.35	0.88	0.66	0.60	1.10	0.78	0.23	0.18	0.26
124 ft	125 mph	5 in	0.32	0.84	0.64	0.58	1.00	0.78	0.21	0.18	0.24

Table 34. Rubber Chevron, Bi-Level Car, 57.0-inch Gage MCAT Results

Rubber Chevron, Bi-Level Car, 57.0" Gage											
Wavelength	Speed	Cant Deficiency	Min Wheel Vertical Load Ratio (0.15)	Maximum Wheel L/V Ratio (1.13)	Maximum Net Axle L/V Ratio	Maximum Truck Side L/V Ratio (0.6)	Maximum Carbody Lateral Peak to Peak Accel (0.65)	Maximum Carbody Vertical Peak to Peak Accel (1.0)	Carbody Lateral (sustained Oscillatory) (0.10)	Carbody Vertical (sustained Oscillatory) (0.25)	Maximum Truck Lateral Accel (0.3)
31 ft	115 mph	3 in	0.63	0.33	0.33	0.25	0.63	0.32	0.12	0.05	0.15
31 ft	115 mph	4 in	0.57	0.37	0.36	0.29	0.68	0.32	0.13	0.05	0.16
31 ft	115 mph	5 in	0.52	0.39	0.38	0.30	0.67	0.32	0.13	0.05	0.16
31 ft	120 mph	3 in	0.58	0.36	0.35	0.28	0.69	0.34	0.12	0.05	0.15
31 ft	120 mph	4 in	0.53	0.38	0.37	0.30	0.69	0.33	0.13	0.05	0.16
31 ft	120 mph	5 in	0.47	0.41	0.40	0.33	0.71	0.33	0.14	0.05	0.17
31 ft	125 mph	3 in	0.59	0.35	0.35	0.28	0.68	0.34	0.11	0.06	0.16
31 ft	125 mph	4 in	0.53	0.38	0.37	0.31	0.72	0.34	0.13	0.06	0.17
31 ft	125 mph	5 in	0.45	0.43	0.41	0.35	0.76	0.34	0.14	0.06	0.17
62 ft	115 mph	3 in	0.54	0.40	0.37	0.32	0.76	0.31	0.13	0.05	0.15
62 ft	115 mph	4 in	0.50	0.45	0.40	0.35	0.78	0.31	0.14	0.05	0.16
62 ft	115 mph	5 in	0.45	0.48	0.43	0.40	0.79	0.31	0.14	0.05	0.17
62 ft	120 mph	3 in	0.58	0.37	0.36	0.29	0.73	0.29	0.13	0.05	0.16
62 ft	120 mph	4 in	0.53	0.40	0.38	0.32	0.76	0.29	0.14	0.05	0.16
62 ft	120 mph	5 in	0.47	0.45	0.41	0.36	0.79	0.29	0.14	0.05	0.16
62 ft	125 mph	3 in	0.58	0.36	0.36	0.29	0.74	0.29	0.13	0.05	0.17
62 ft	125 mph	4 in	0.51	0.40	0.39	0.33	0.76	0.29	0.13	0.05	0.17
62 ft	125 mph	5 in	0.43	0.45	0.43	0.37	0.78	0.29	0.14	0.05	0.18
124 ft	115 mph	3 in	0.32	0.50	0.46	0.45	0.84	0.73	0.17	0.17	0.18
124 ft	115 mph	4 in	0.27	0.51	0.47	0.47	0.88	0.73	0.18	0.17	0.18
124 ft	115 mph	5 in	0.20	0.50	0.46	0.45	0.81	0.72	0.17	0.17	0.16
124 ft	120 mph	3 in	0.27	0.62	0.54	0.55	1.08	0.82	0.24	0.19	0.25
124 ft	120 mph	4 in	0.22	0.60	0.54	0.54	1.04	0.82	0.22	0.19	0.23
124 ft	120 mph	5 in	0.18	0.58	0.52	0.52	0.96	0.82	0.21	0.19	0.21
124 ft	125 mph	3 in	0.25	0.84	0.71	0.73	1.53	0.89	0.48	0.21	0.38
124 ft	125 mph	4 in	0.21	0.75	0.61	0.62	1.25	0.89	0.35	0.21	0.32
124 ft	125 mph	5 in	0.20	0.68	0.59	0.61	1.13	0.89	0.27	0.21	0.29

3.14.3 Static Wheel Load Equalization Results

Conical Spring Wheel Load Equalization Results

Figure 42 shows the wheel drop results for the conical spring truck under the single-level car. The figure shows the results of wheel load distribution as a function of incremental wheel drop at each wheel position of the trailing truck; axles 3 and 4. The minimum vertical wheel loads are at about 16 percent of static wheel load at 3 inches. The results show symmetrical trends from side to side and axle to axle.

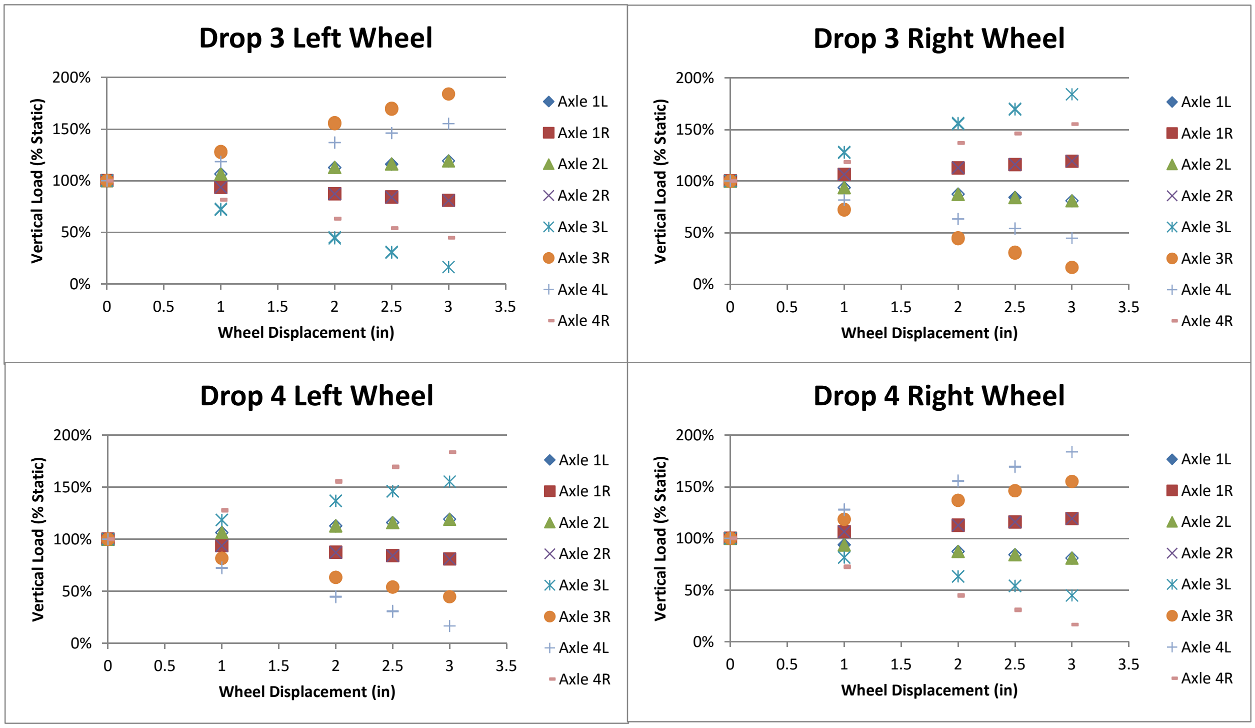

Figure 42. Conical Spring, Single-Level Car, Wheel Drop Results, Axles 3 & 4

Figure 43 shows the wheel lift results for the conical spring truck under the single-level car. The figure shows the results of wheel load distribution as a function of incremental wheel lift at each wheel position of the trailing truck; axles 3 and 4. The minimum vertical wheel loads are at about 16 percent of static wheel load at 3 inches. The results show symmetrical trends from side to side and axle to axle and are similar to the wheel drop results shown in Figure 42.

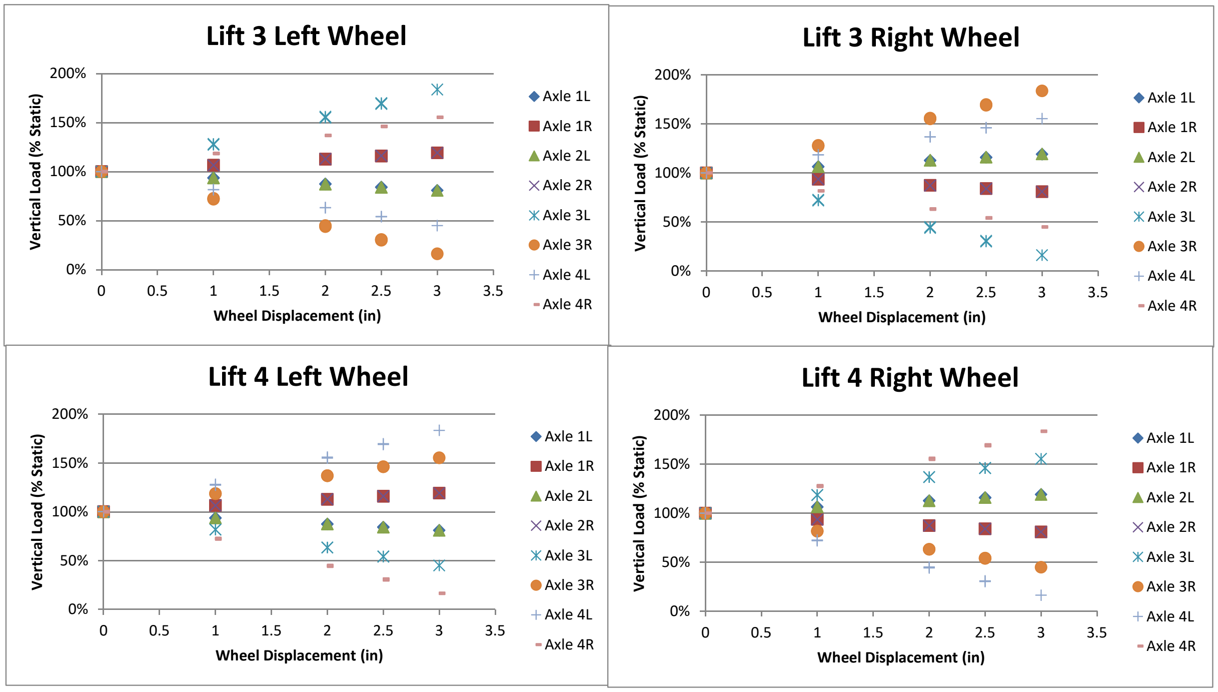

Figure 43. Conical Spring, Single-Level Car, Wheel Lift Results, Axles 3 & 4

Figure 44 and Figure 45 show the results for the conical spring truck under the bi-level car for both wheel drop and wheel lift, respectively. Figure 45 shows the results of wheel load distribution as a function of incremental wheel lift at each wheel position of the trailing truck; axles 3 and 4. The minimum vertical wheel loads are at about 47 percent of static wheel load at 3 inches, which is substantially higher than the single-level car due primarily to the heavier carbody weight of the bi-level car.

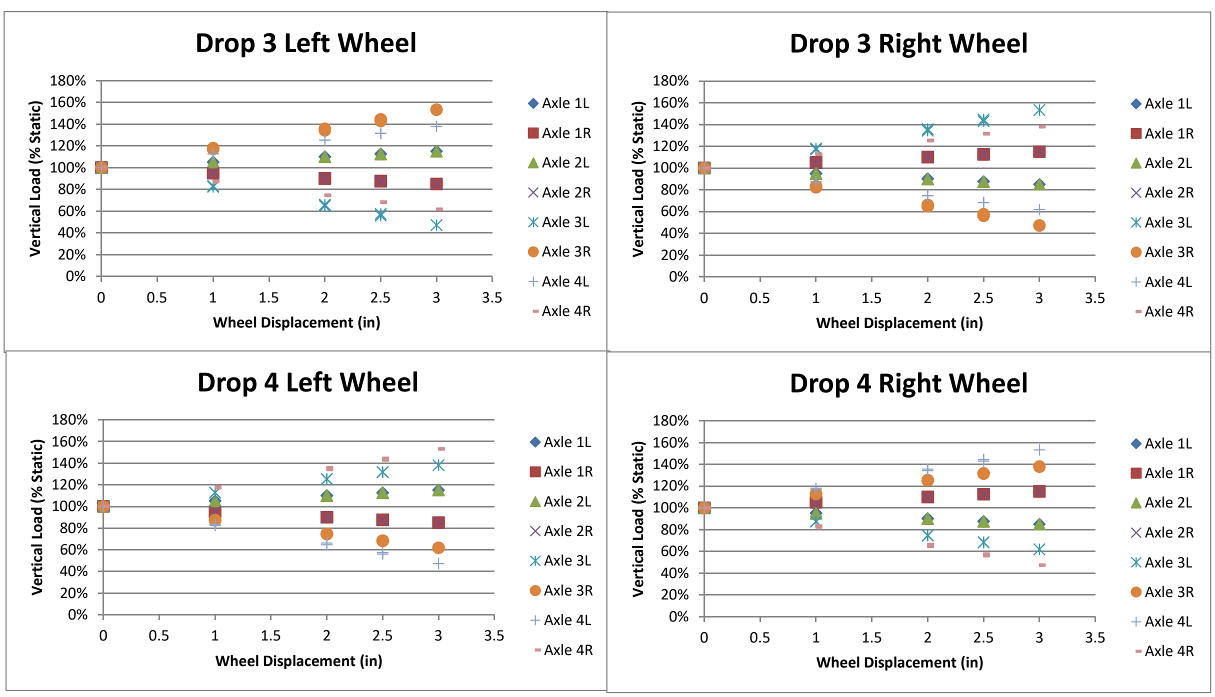

Figure 44. Conical Spring, Bi-Level Car, Wheel Drop Results, Axles 3 & 4

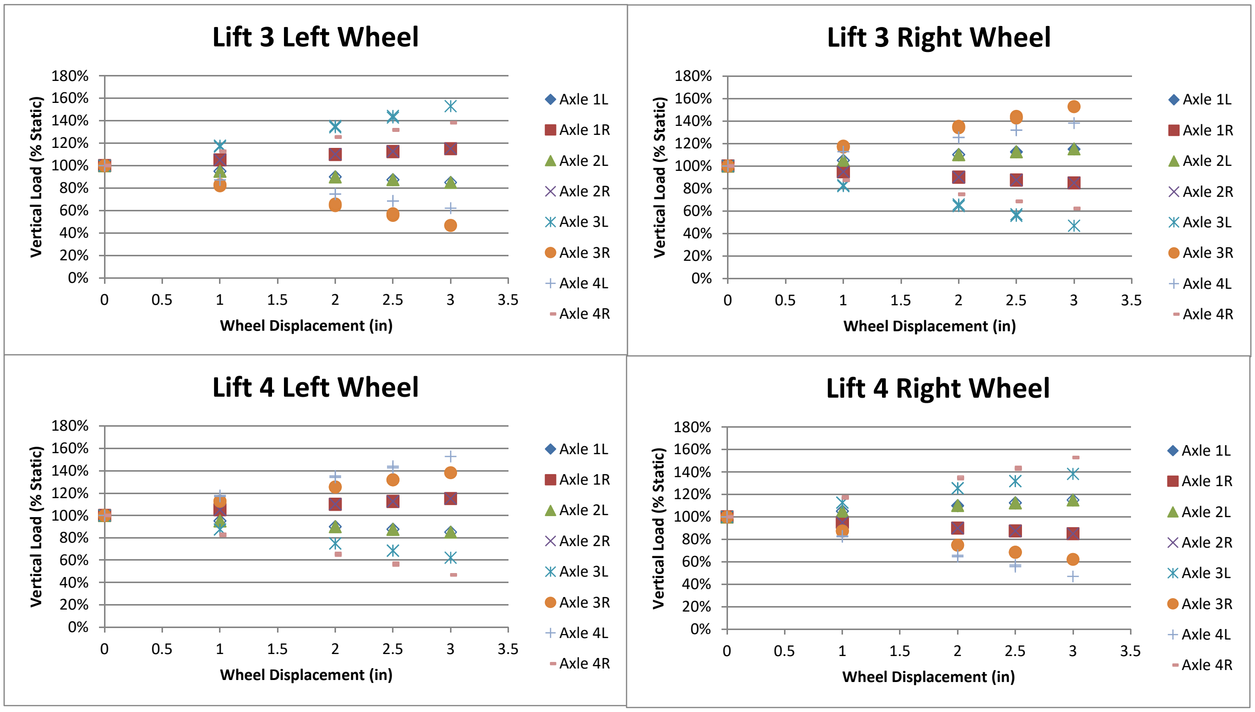

Figure 45. Conical Spring, Bi-Level Car, Wheel Lift Results, Axles 3 & 4

Table 35 shows a summary of the worst case vertical wheel load for all truck types for the wheel load equalization simulations. The results clearly show the equalizer beam design yields the best wheel load equalization. This is not surprising as this is one of the design features of the equalizer beam truck type. The equalizer beam truck meets the APTA criteria for both single-level and bi-level cars. The journal spring suspension shows wheel lift at 3 inches whereas the remaining truck designs exceed the minimum limit of 35 percent of static wheel load. The plots for the remaining truck types, similar to those shown in Figure 41 through Figure 45, are included in Appendix G.

Table 35. Wheel Load Equalization Summary

Truck Type	Single-Level	Bi-Level
Conical Spring	16.18%	46.73%
Equalizer Beam	49.19%	63.37%
Journal Spring	0.00%	31.60%
Radial Arm	16.85%	44.30%
Rubber Chevron	15.39%	47.20%

Table 35 shows that the journal spring primary suspension truck under the single-level car shows wheel lift. To improve the journal spring performance of wheel load equalization along with low speed wheel climb derailment (Section 3.14.5), a vertical suspension stiffness parameter variation was made by reducing the vertical primary stiffness by 30 percent. Figure 46 shows the axle 3 left wheel lift results with the primary suspension at nominal value (upper plot) and with the vertical suspension with a 30 percent lower stiffness. Note that by reducing the vertical primary stiffness, the result is greatly improved; the minimum vertical wheel load was formerly at 0 percent, and it is now at approximately 23 percent.

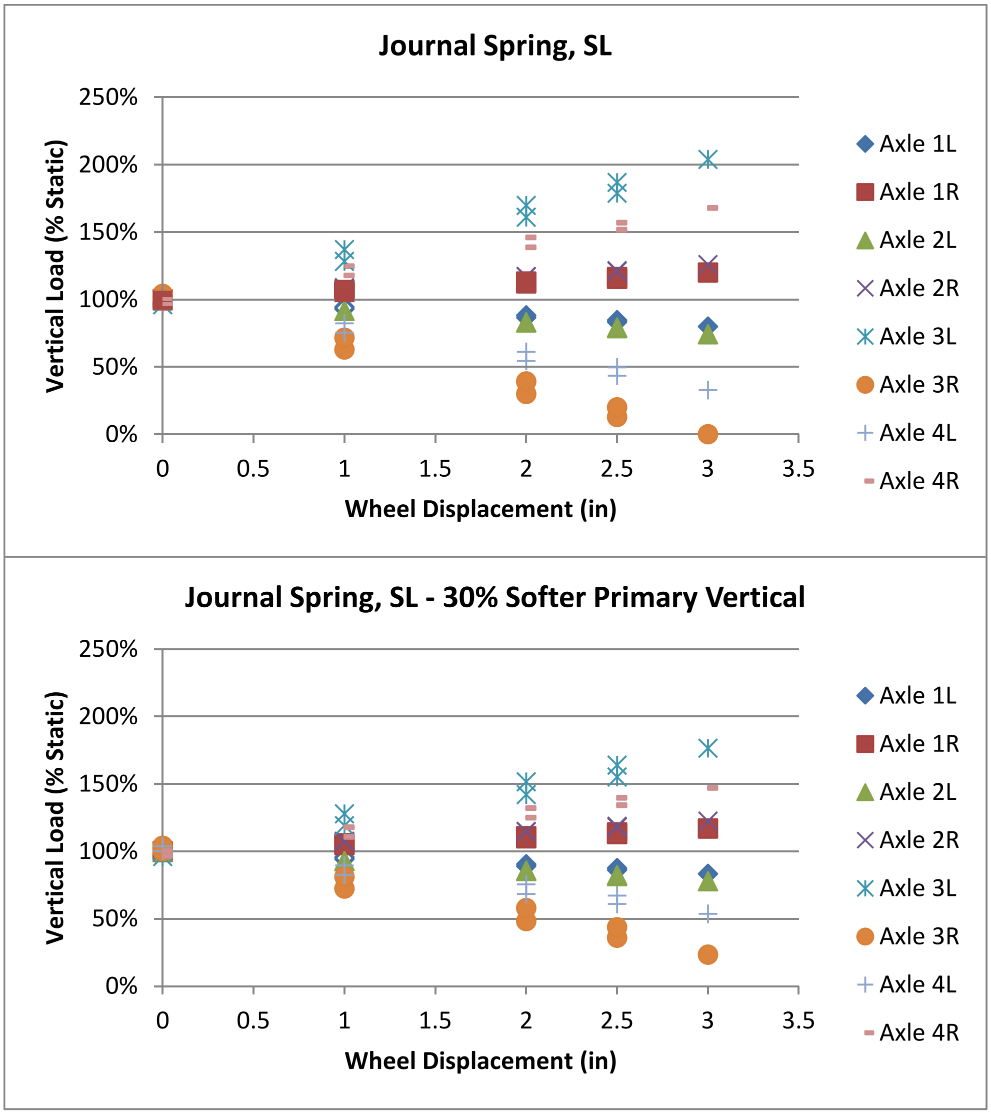

Figure 46. Journal Spring Wheel Load Equalization, Primary Vertical Stiffness Parameter Variation, Wheel Lift Axle 3 Left

3.14.4 Static Lean Results

Figure 47 shows the single-level carbody roll angle for incremental increases in superelevation. The results are nearly indistinguishable from truck design to truck design and are all well below the limit of 8.6 degrees. Figure 48 shows the single-level carbody minimum vertical wheel load as a percent of static wheel load for incremental increases in superelevation. The result shows the rubber chevron design is right at the limit at 6 inches of superelevation and exceeds the limit of 60 percent of static wheel load at 7 inches of superelevation. The other designs all yield similar results but do not exceed the limit.

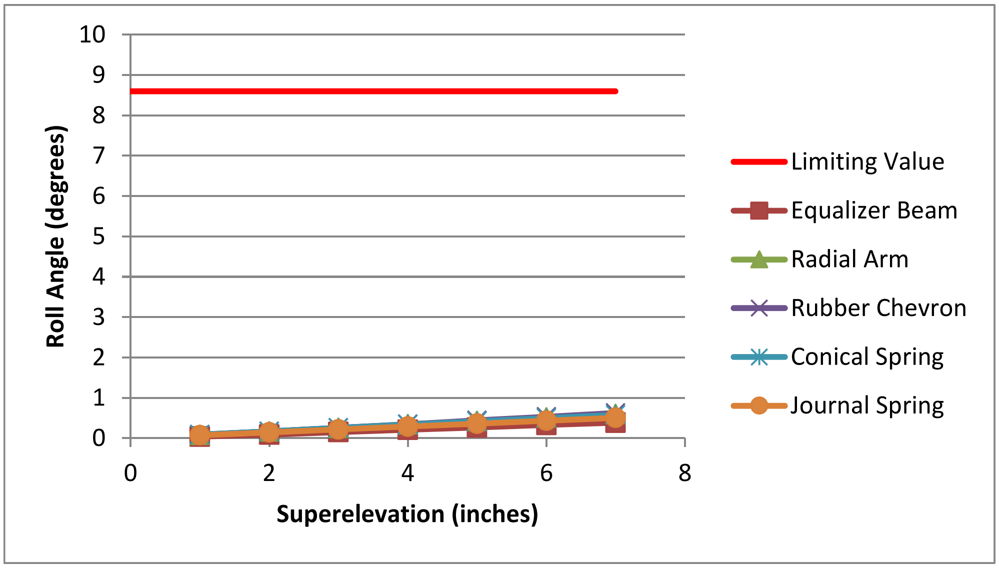

Figure 47. Single-Level Static Lean Simulations, Maximum Carbody Roll Angle

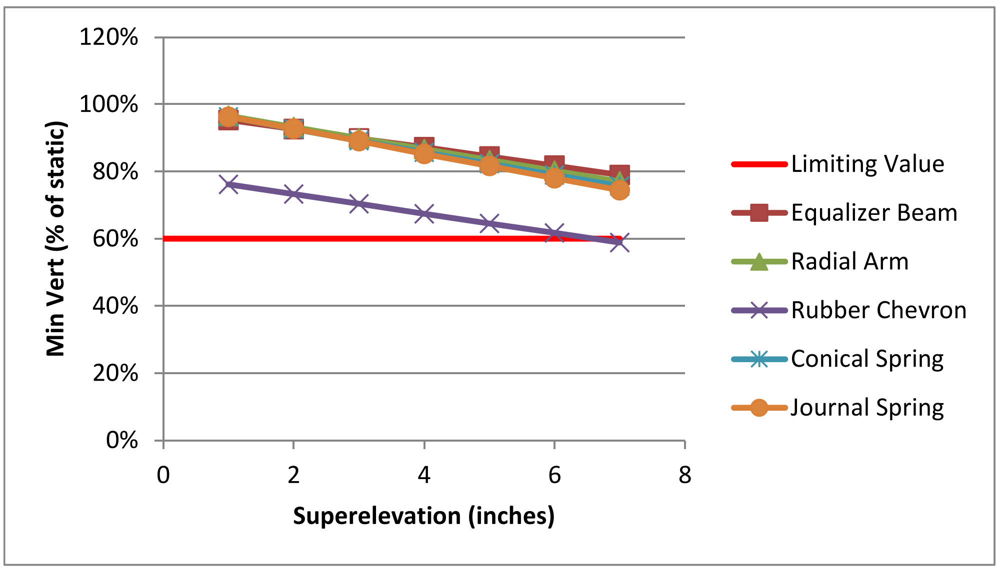

Figure 48. Single-Level Static Lean Simulations, Minimum Vertical Wheel Load

Figure 49 shows the bi-level carbody roll angle for incremental increases in superelevation. This results in a more discernable difference in carbody roll angle as a function of increasing superelevation, but all results are well below the limit of 8.6-degrees. Figure 50 shows the bi-level minimum vertical wheel load as a percent of static wheel load for incremental increases in superelevation. The result shows all truck designs very near the limit at 7 inches of superelevation, which is likely because the bi-level car has a higher center-of-gravity than the single-level car.

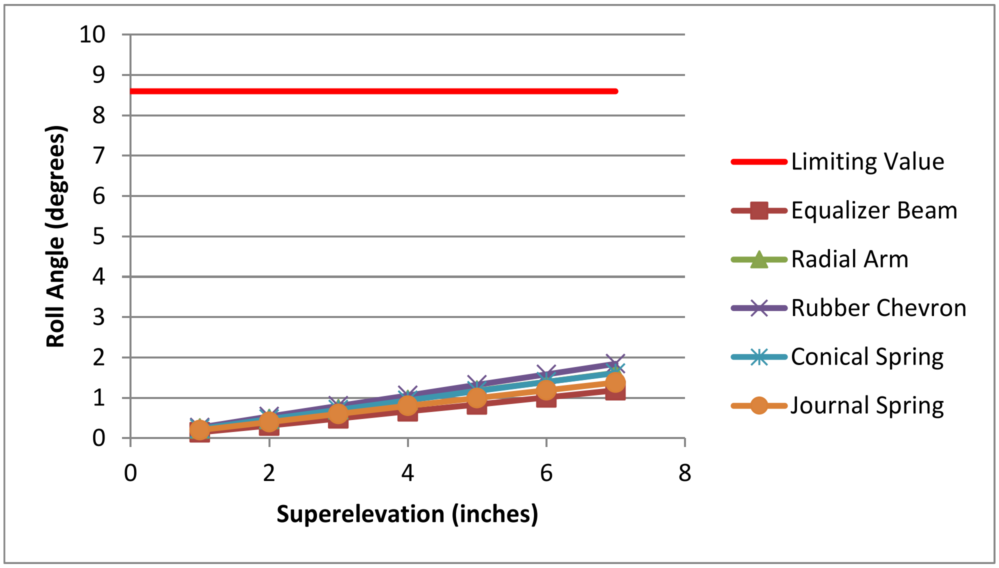

Figure 49. Bi-Level Static Lean Simulations, Maximum Carbody Roll Angle

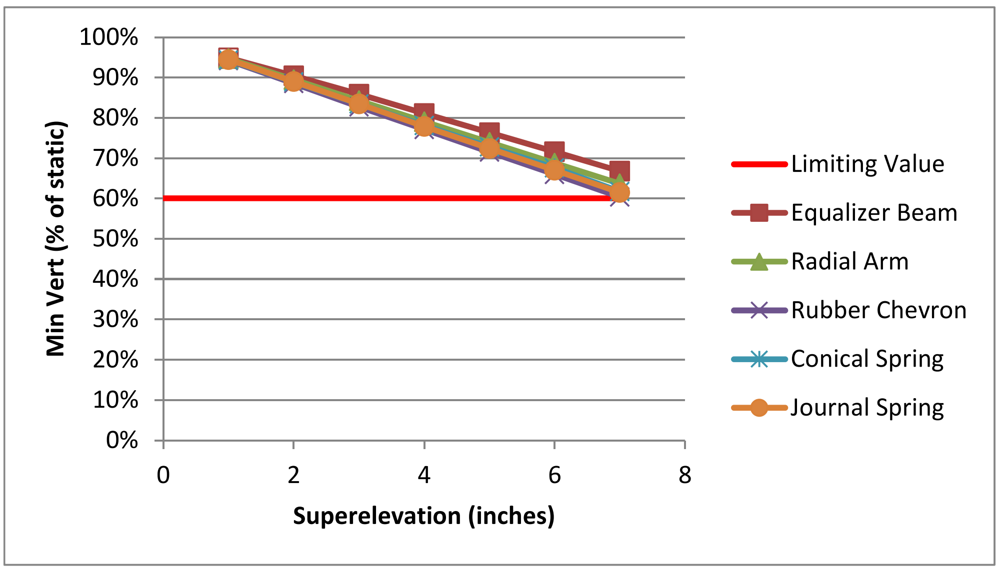

Figure 50. Bi-Level Static Lean Simulations, Minimum Vertical Wheel Load

3.14.5 Low-Speed Wheel Climb Derailment Results

The railroad industry has different flange climb derailment criteria; passenger versus freight, time-based limit versus distance-based limit, all of which are strongly dependent on wheelset angle of attack [70] [71]. The results presented in this section are for different types of window criteria, two distance-based limits and one time-based limit: (1) a 3-foot window (AAR Chapter 11), (2) a 5-foot window (49 CFR § 213.333), and (3) a 50-msec window (AAR Chapter 11). Also, the maximum value is included. Because the safety advisory evaluation is at low speed (5 mph [8 km/h]), the distance duration criteria may be too liberal for these low speed, large angle of attack evaluations. Research conducted by TTCI for FRA, AAR, and the Transit Cooperative Research Program indicates that flange climb can occur in much shorter distances at low speed [70–72]. Conversely, the time duration criterion of 50 msec has been shown to be too short for small angles of attack and higher speeds. Figure 51 shows a plot of the various flange climb derailment criteria as a function of speed. The plot shows the 50-msec criteria to be the most conservative at low speeds, below 40 mph (64 km/h).

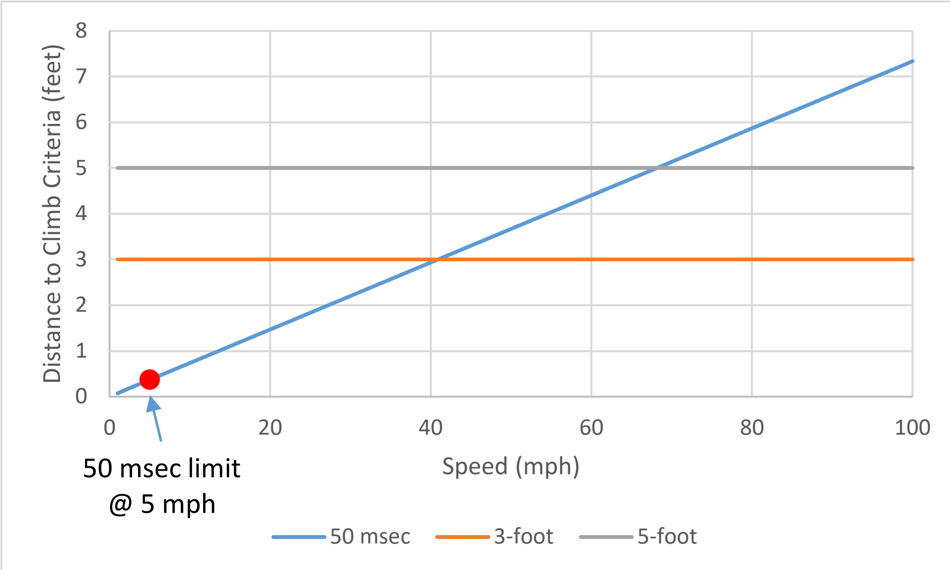

Figure 51. Flange Climb Derailment Criteria

Figure 52 through Figure 72 show the single wheel L/V ratio and minimum vertical wheel load results for the FRA low-speed safety advisory simulation. Each figure shows the results of four different wavelength perturbations for a range of perturbation amplitudes, all in a 12-degree curve at 5 mph (8 km/h). To demonstrate and emphasize the importance of an appropriate safety criteria, four different evaluation methods are shown: 50-msec, 3-foot, 5-foot, and maximum L/V. It can be noted that the maximum L/V and 50-msec results are virtually identical.

Figure 52 shows the results for the conical spring truck under the single-level car. The results shows predicted derailment for the 10-foot and 20-foot wavelengths at 2.5-inch perturbation amplitude and also predicted derailment at 3-inch amplitude for the 40-foot wavelength. The results also highlight the distinguishable difference of the evaluation criteria for the shorter wavelength perturbations. For example, the 50 msec result for the 10-foot wavelength shows a trend that exceeds the Nadal Limit above 1.5 inches, trending upward to the point of predicted derailment at 2.5 inches. However, both the 3-foot and 5-foot criterion show a downward turn at 1.5 inches, not only for the 10-foot wavelength, but for the 20-foot wavelength as well. These results suggest that using the longer wavelength criteria for a low speed derail could be incorrect. The results also show that the differences between evaluation criteria become less distinguishable for the longer wavelength perturbations.

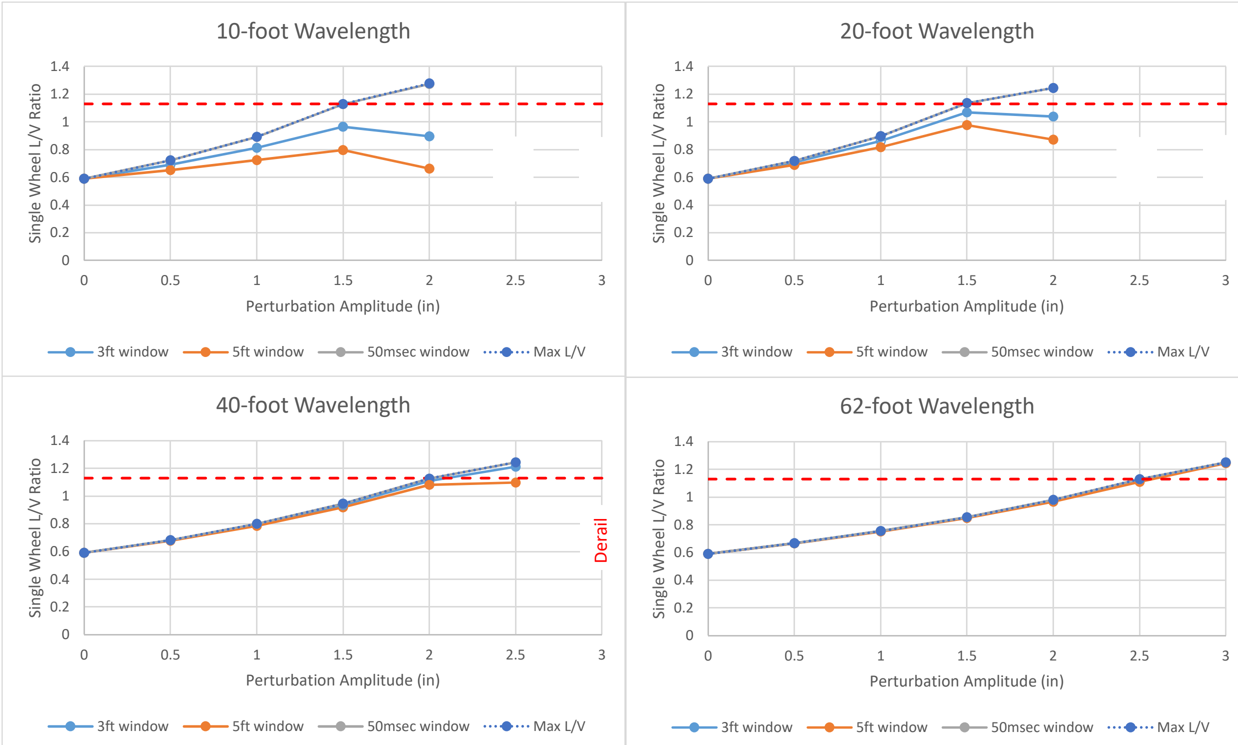

Figure 52. Low Speed Safety Advisory, Conical Spring, Single-Level Car, Single Wheel L/V Ratio

Figure 53 shows the corresponding minimum vertical wheel load results for the conical spring design under the single-level car. The minimum vertical wheel load results shown are a percentage of static vertical wheel loads. The results show a downward trend with an increase in perturbation amplitude for all wavelengths, with the shorter wavelengths generating lower minimum vertical loads, and derailment at the 2.5- and 3-inch amplitudes.

Many safety criteria use 10 percent as a safety limit for minimum vertical wheel load criteria, and at 2-inch perturbation amplitude, the minimum vertical wheel load is about 30 to 40 percent for the 10-foot and 20-foot wavelengths while at 2.5-inch perturbation amplitude derailment occurs. This suggests that the minimum wheel criterion alone is not a good predictor of impending derailment, and it highlights the need for L/V criteria that accurately predicts impending derailment.

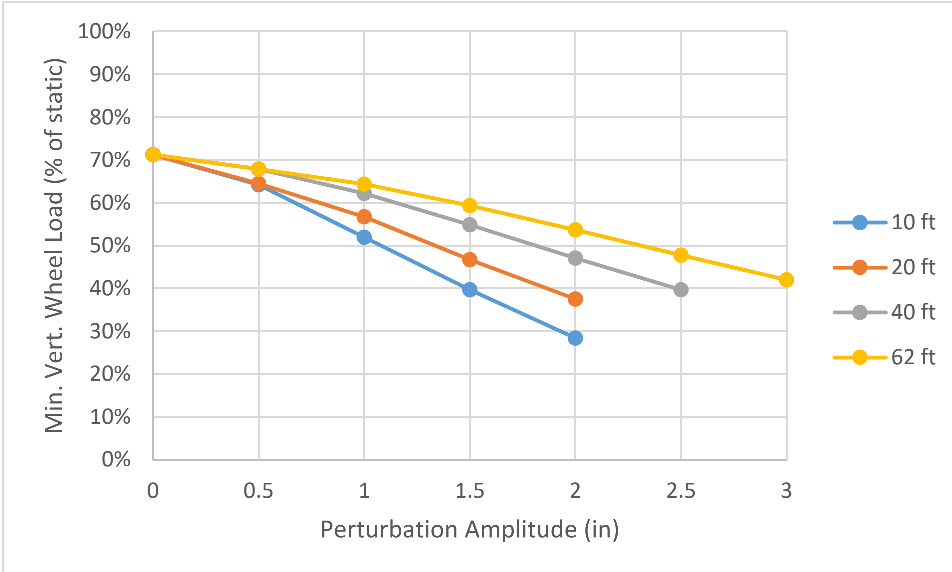

Figure 53. Low Speed Safety Advisory, Conical Spring, Single-Level Car, Minimum Vertical Wheel Load

Figure 54 shows the results for the conical spring design under the bi-level car. The results show that the Nadal limit is exceeded at 2.5 inches for the 10-foot and 20-foot wavelength cases. The 10-foot and 20-foot wavelength results also show a drop in 3-foot and 5-foot L/Vs at the 3-inch amplitude, which suggests these criteria may be incorrect for analyzing lower speed derailments.

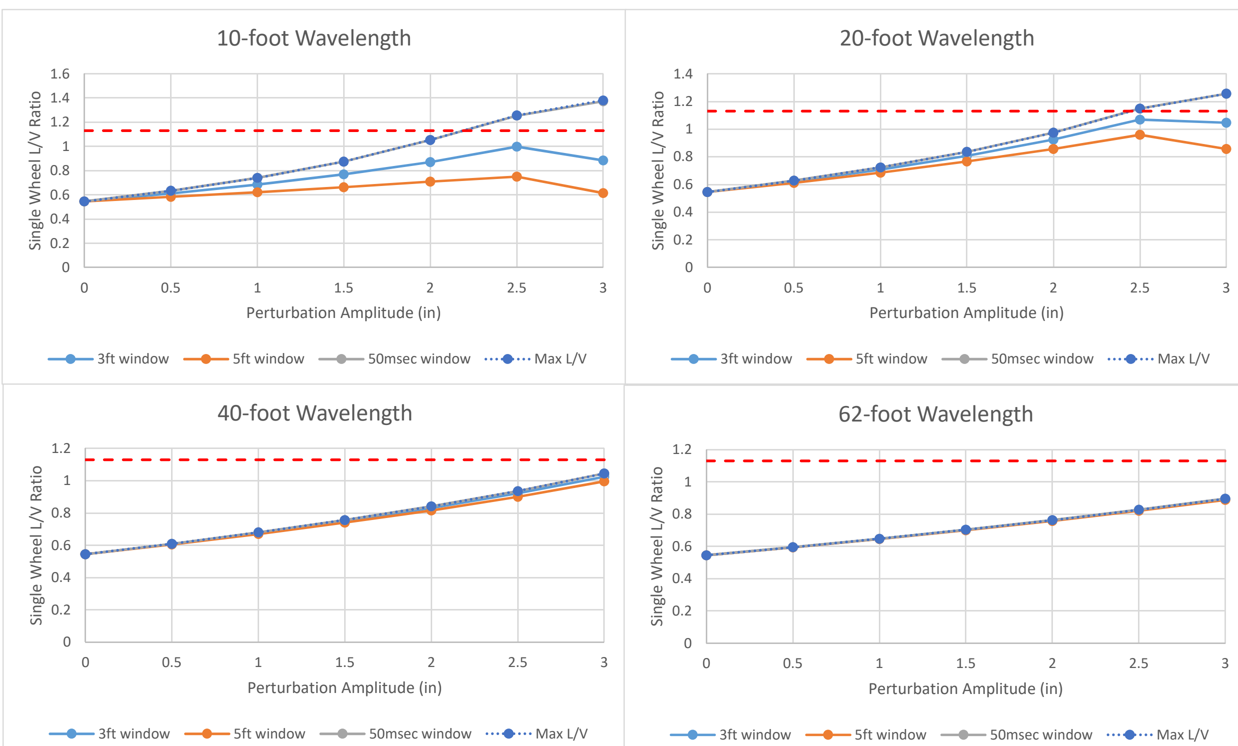

Figure 54. Low Speed Safety Advisory, Conical Spring, Bi-Level Car, Single Wheel L/V Ratio

Figure 55 shows the minimum vertical wheel load results for the bi-level car with the conical spring truck design. The results show a decreasing trend as a function of perturbation amplitude. There is little difference between the 40-foot and 62-foot wavelength results. The 10-foot wavelength results show about 30 percent remaining wheel load at 3-inch amplitude.

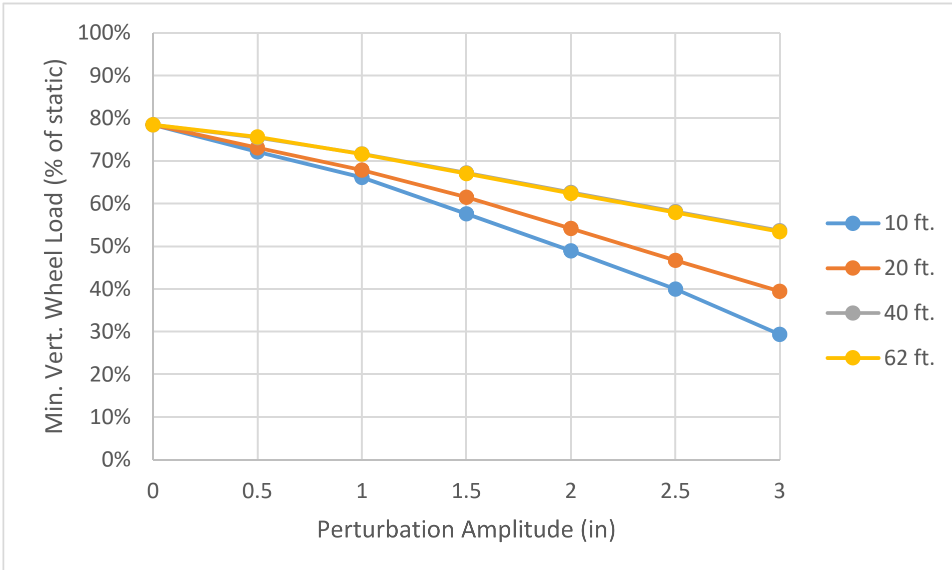

Figure 55. Low Speed Safety Advisory, Conical Spring, Bi-Level Car, Minimum Vertical Wheel Load

Figure 56 shows the results for the equalizer beam truck design for the single-level car. The results show predicted derailment for the 10-foot and 20-foot wavelength at the 3-inch perturbation amplitude. The Nadal limit is exceeded at the 3-inch amplitude for both the 40-foot and 62-foot wavelengths. The 10-foot wavelength for the 3-foot and 5-foot L/V results are much lower than for the 50 msec results, and are well below the limit at the 2.5-inch amplitude, which suggests that these criteria may be incorrect for predicting the derailment that occurs at the 3-inch amplitude.

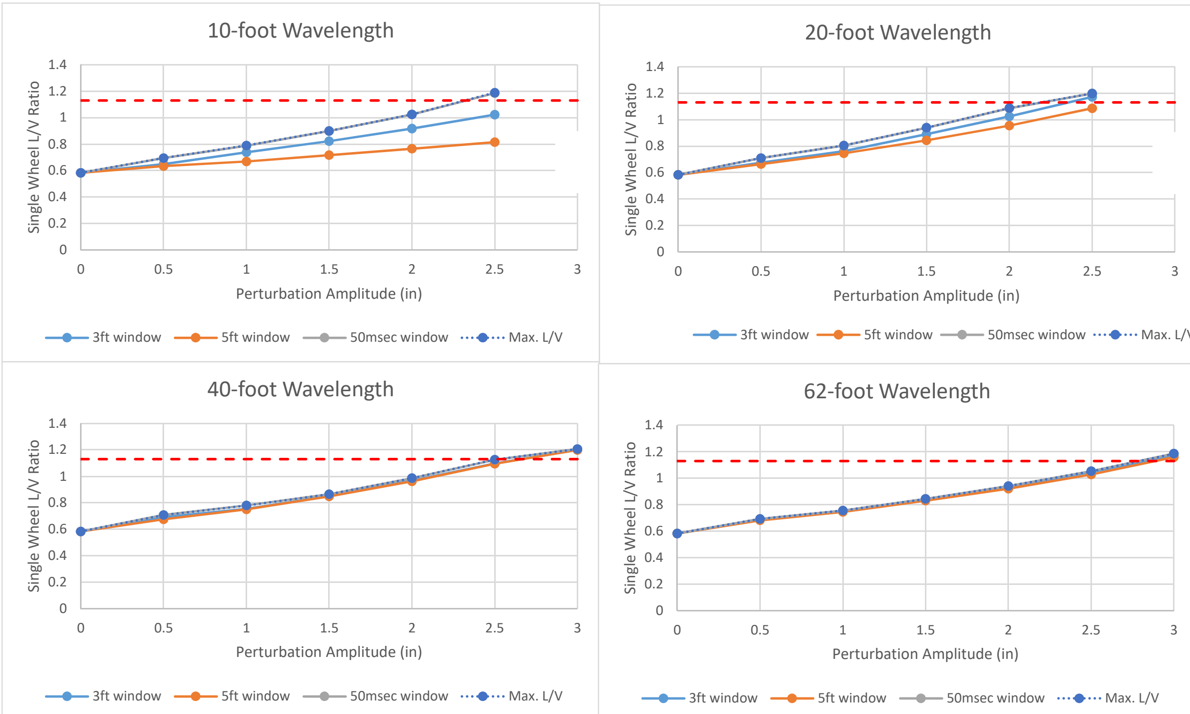

Figure 56. Low Speed Safety Advisory, Equalizer Beam, Single-Level Car, Single Wheel L/V Ratio

Figure 57 shows the minimum vertical wheel load results for the equalizer beam design for the single-level car. The result shows the 10-foot wavelength with only slightly lower minimum vertical loads than the longer wavelengths, which are all very similar. Again, the interesting thing to note here is the minimum vertical loads are well above 10 percent, but still derail at the larger amplitudes for the 10-foot and 20-foot wavelengths, which suggests that the 10 percent minimum wheel load criterion may not be a good predictor of impending flange climb derailment.

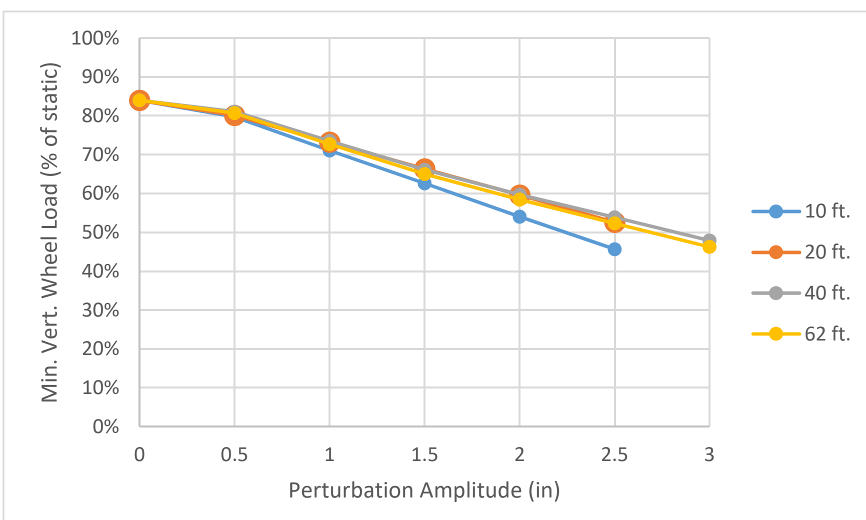

Figure 57. Low Speed Safety Advisory, Equalizer Beam, Single-Level Car, Minimum Vertical Wheel Load

[Figure 58](#) shows the wheel L/V ratios for equalizer beam design under the bi-level car. The 50 msec result is just at the Nadal limit for the 10-foot wavelength at the 3-inch perturbation amplitude. All remaining results are very similar, showing an increasing trend as a function of increasing amplitude, but not much difference with increasing wavelength. The 10-foot wavelength for the 3-foot and 5-foot L/V results are widely separated, much lower than for the 50 msec results, and well below the limit at the 3-inch amplitude, which suggests that these criteria may be incorrect for evaluating derailment safety.

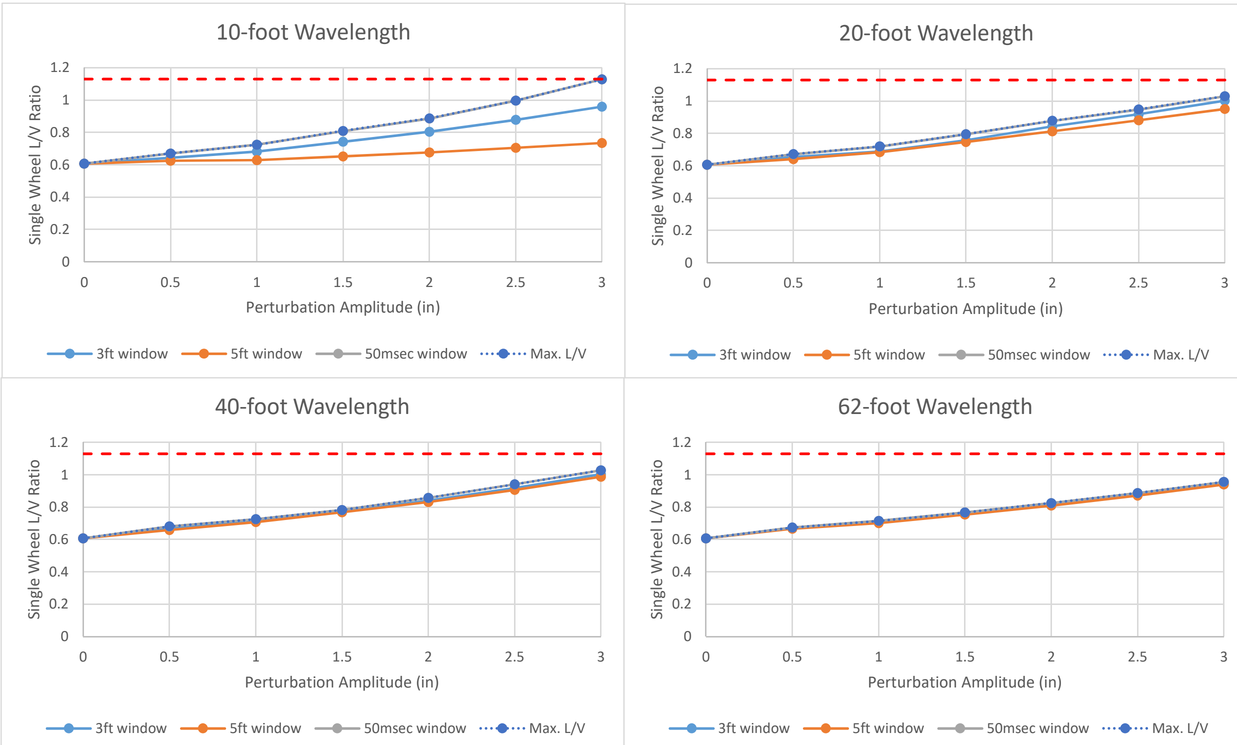

Figure 58. Low Speed Safety Advisory, Equalizer Beam, Bi-Level Car, Single Wheel L/V Ratio

Figure 59 shows the minimum vertical wheel load results for the equalizer beam design under the bi-level car. This result is slightly different from the other cases, because this result shows the 20-foot wavelength perturbation result with the best wheel load. The 10-foot wavelength perturbation generates the lowest minimum vertical wheel load, and the 40-foot and 62-foot results are very similar to each other, but the 20-foot wavelength generates a slightly higher minimum vertical wheel load.

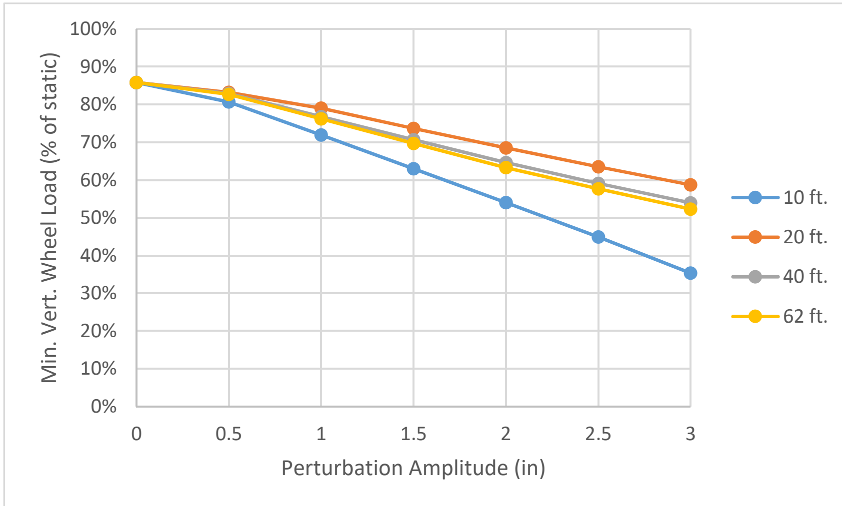

Figure 59. Low Speed Safety Advisory, Equalizer Beam, Bi-Level Car, Minimum Vertical Wheel Load

Figure 60 shows the results for the journal spring truck design under the single-level car. The result shows predicted derailment at 2-inch perturbation amplitude for the 10-, 20-, and 40-foot wavelength perturbations and predicted derailment at 2.5-inch perturbation amplitude for the 62-foot wavelength perturbation. The 10-foot wavelength perturbations for 3-foot and 5-foot L/V results are widely separated, much lower than the 50 msec results, and well below the limit at the 1.5-inch amplitude, which suggests that these criteria may be incorrect for predicting the derailment that occurs at 2.0-inch amplitude.

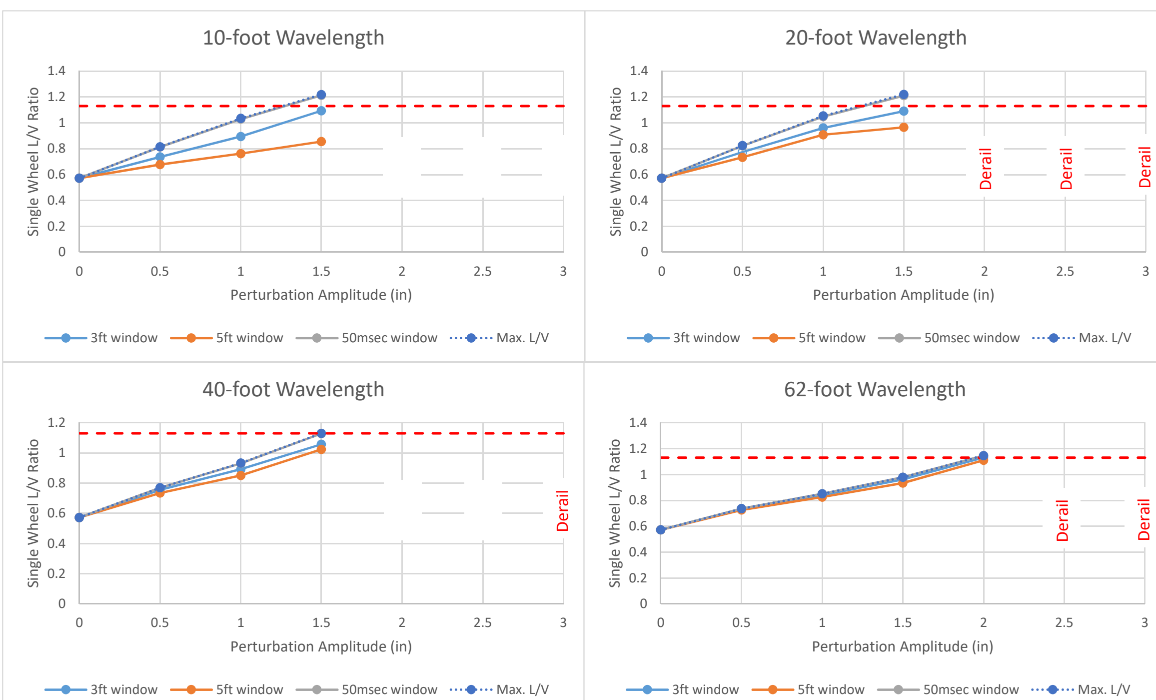

Figure 60. Low Speed Safety Advisory, Journal Spring, Single-Level Car, Single Wheel L/V Ratio

Figure 61 shows the minimum vertical wheel loads for the journal spring design under the single-level car. These results show similar downward trends as a function of perturbation amplitude, but the decrease is more rapid. Derailment was predicted at all wavelengths, which suggests that the 10 percent minimum wheel load criterion may not be a good predictor of impending flange climb derailment.

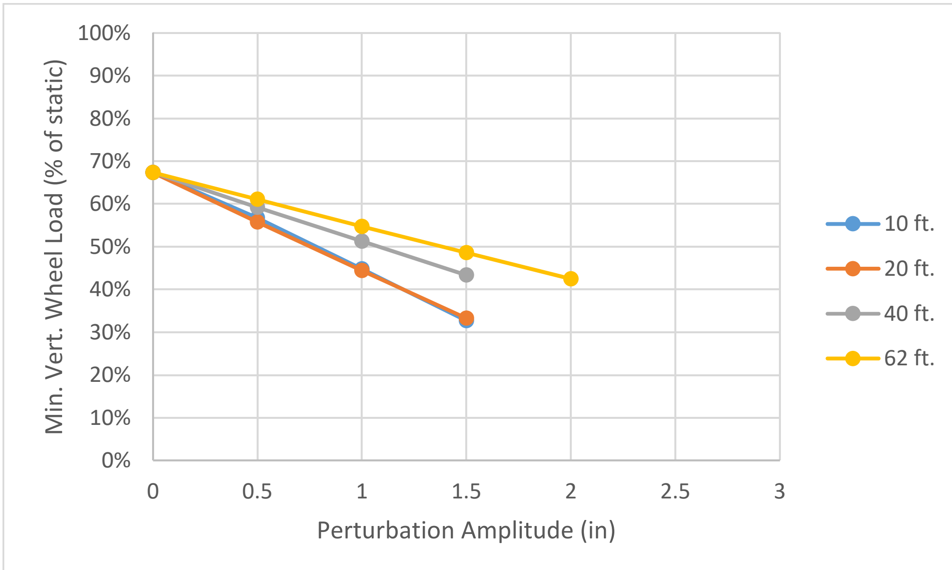

Figure 61. Low Speed Safety Advisory, Journal Spring, Single-Level Car, Minimum Vertical Wheel Load

Because the single-level journal spring case generated the worst results in the low speed derailment simulations and the worst performance in the wheel load equalization simulations, efforts to improve the performance were evaluated by reducing the primary vertical stiffness by 30 percent. The results in the wheel load equalization showed a notable improvement (see Section 3.14.3).

Figure 62 shows the single wheel L/V ratio results for the journal spring design on the single-level car with nominal primary vertical stiffness compared to primary vertical stiffness with 30 percent reduction. The results shown are for the 50 msec evaluation criteria and show a slight improvement. For the 10-foot, 40-foot, and 62-foot wavelength perturbations, the derailment amplitude is better by 1/2-inch increments, and for all wavelengths the results are slightly lower. Although this was not an exhaustive parameter variation, it does demonstrate how tuning of the suspension could improve performance in specific regimes.

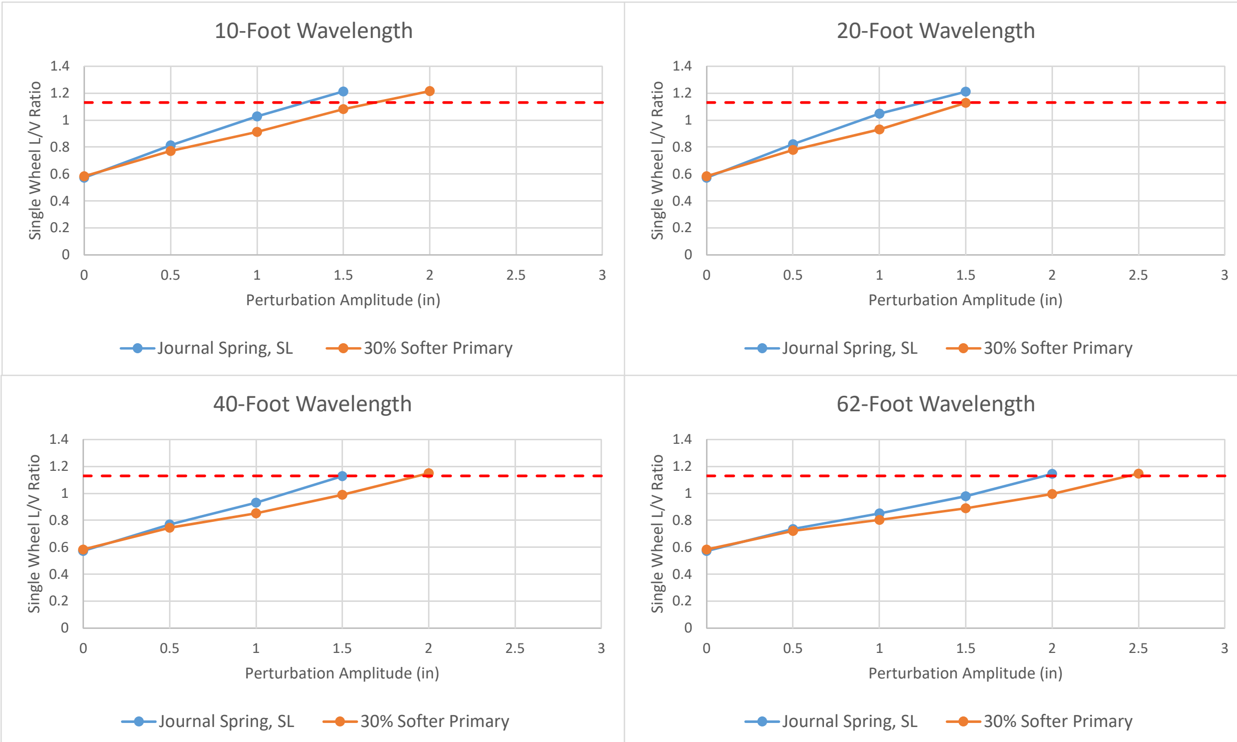

Figure 62. Low Speed Safety Advisory, Journal Spring, Single-Level Car, Primary Vertical Stiffness Parameter Variation

Figure 63 shows the results for the journal spring truck design under the bi-level car. These results show predicted derailment at 2.5 inches for the 10- and 20-foot wavelength and at 3.0 inches for the 40-foot wavelength perturbation. The 10-foot wavelength perturbation for 3-foot and 5-foot L/V results are much lower than the 50 msec results, and show a drop well below the limit at the 2.0-inch amplitude, which suggests that these criteria may be incorrect for predicting the derailment that occurs at the 2.5-inch amplitude.

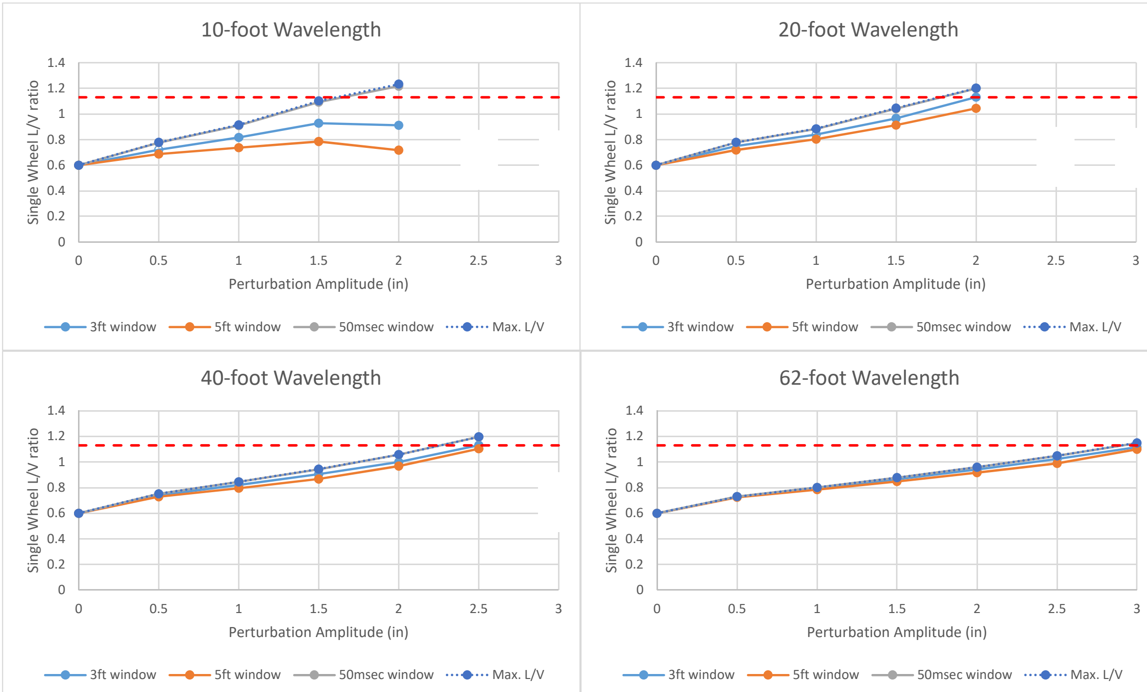

Figure 63. Low Speed Safety Advisory, Journal Spring, Bi-Level Car, Single Wheel L/V Ratio

Figure 64 shows the minimum vertical wheel loads for the journal spring design under the bi-level car. These results show similar downward trends as a function of perturbation amplitude, with the 40-foot and 62-foot wavelength perturbations showing similar trends, but the 40-foot wavelength perturbation derails at the 3-inch amplitude. Derailment was predicted at the 10-foot, 20-foot, and 30-foot wavelength perturbations, which suggests that the 10 percent minimum wheel load criterion may not be a good predictor of impending flange climb derailment.

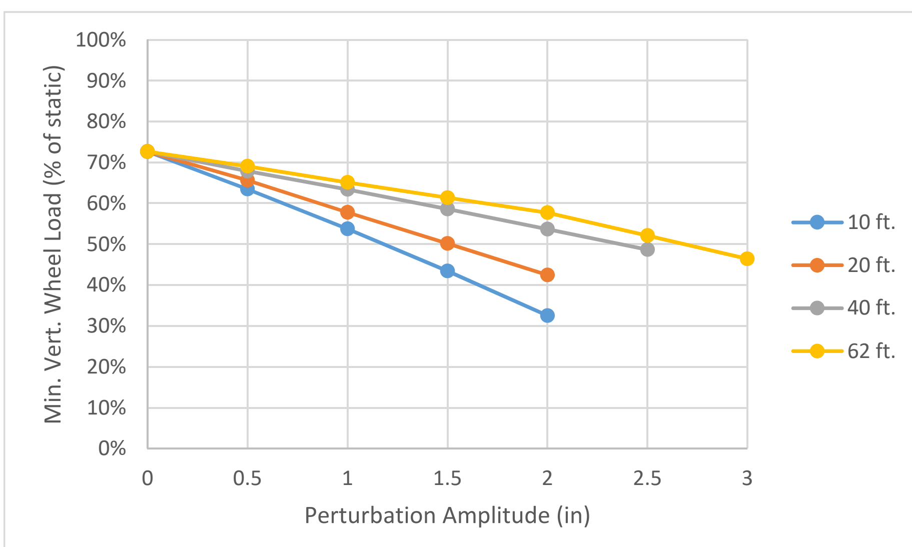

Figure 64. Low Speed Safety Advisory, Journal Spring, Bi-Level Car, Minimum Vertical Wheel Load

[Figure 65](#) shows the single wheel L/V ratio results for the radial arm design under the single-level car. The results show predicted derailment for the 10-foot and 20-foot wavelength perturbations at 2.5 inches and at 3.0 inches for the 40-foot wavelength perturbation. The 10-foot wavelength for the 3-foot and 5-foot L/V results are lower than the 50 msec results, widely separated, and well below the limit at the 2.0-inch amplitude, which suggests that these criteria may be incorrect for predicting the derailment that occurs at the 2.5-inch amplitude.

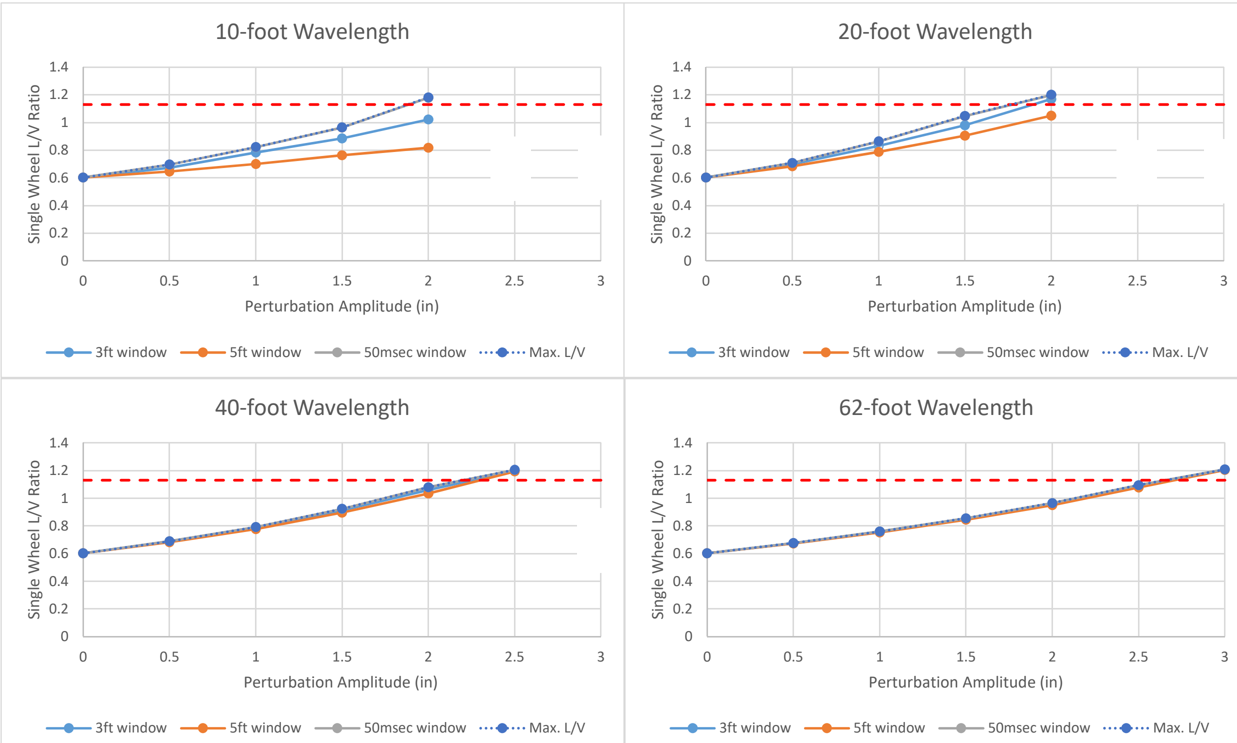

Figure 65. Low Speed Safety Advisory, Radial Arm, Single-Level Car, Single Wheel L/V Ratio

Figure 66 shows the minimum vertical wheel load results for the radial arm design under the single-level car. The results show the 10-foot wavelength with a 40 percent wheel load at 2-inch perturbation amplitude. Derailment was predicted at the10-foot, 20-foot, and 30-foot wavelengths, which suggests that the 10 percent minimum wheel load criterion may not be a good predictor of impending derailment.

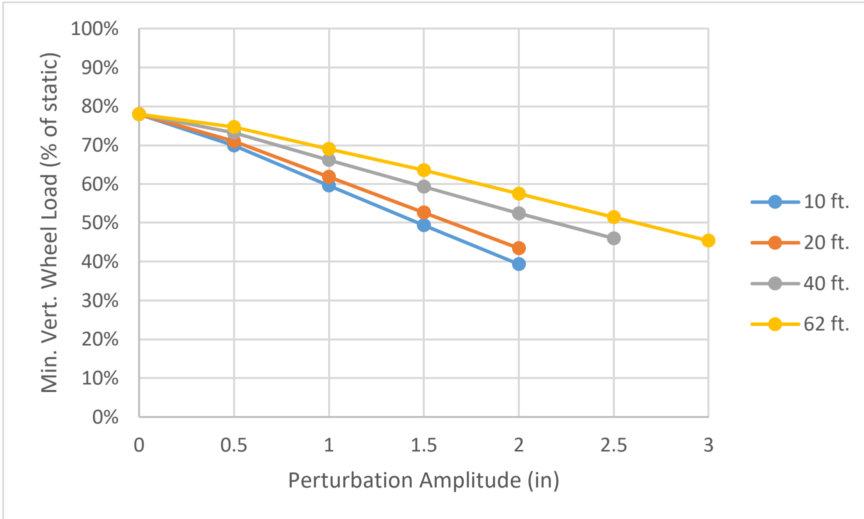

Figure 66. Low Speed Safety Advisory, Radial Arm, Single-Level Car, Minimum Vertical Wheel Load

Figure 67 shows the bi-level car wheel L/V ratio results for the radial arm design. The results show predicted derailments at the 3-inch amplitude for the 10-foot wavelength case. The 3-inch amplitude perturbation shows an exceedance on the 20-foot wavelength. The 40-foot and 62-foot wavelengths are below the Nadal limit for all criteria. The 10-foot wavelength for the 3-foot and 5-foot L/V results are much lower than the 50 msec results, and well below the limit at the 2.5-inch amplitude, which suggests that these criteria may be incorrect for predicting the derailment that occurs at the 3.0-inch amplitude.

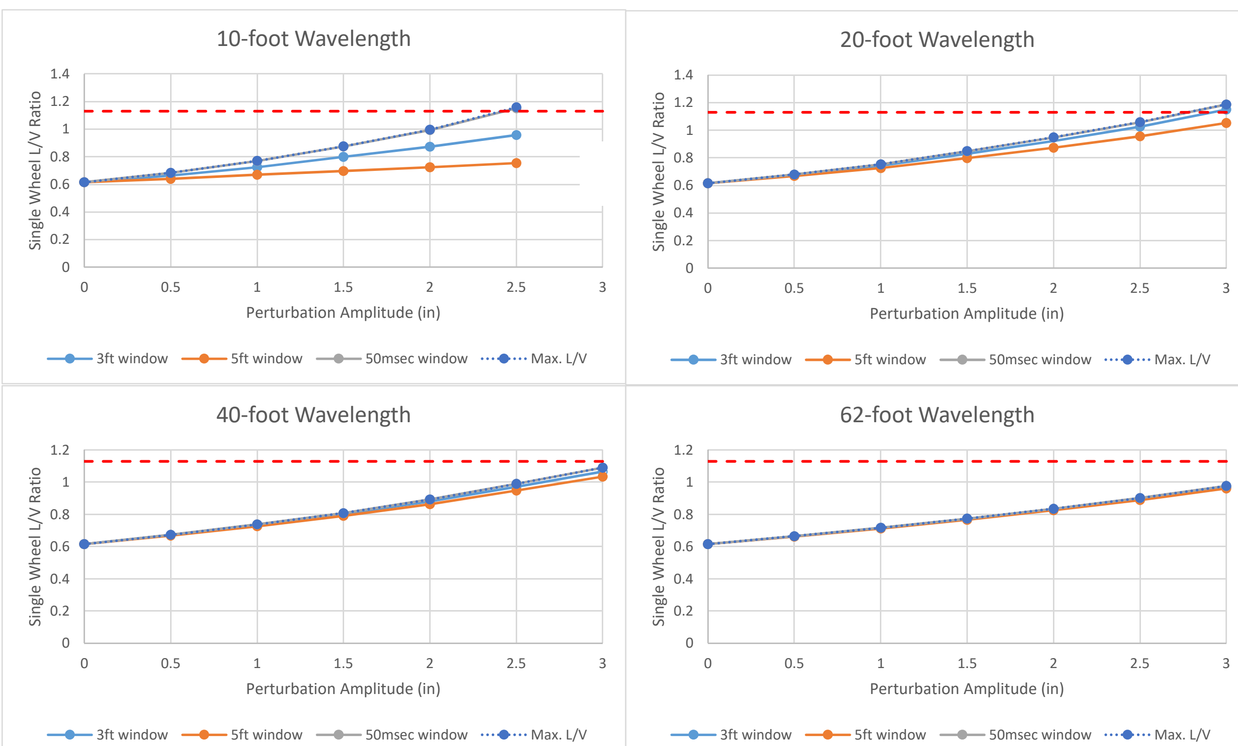

Figure 67. Low Speed Safety Advisory, Radial Arm, Bi-Level Car, Single Wheel L/V Ratio

Figure 68 shows the minimum vertical wheel load results for the radial arm suspension under the bi-level car. The results show the 10-foot wavelength generates 40 percent wheel load at 2.5 inches but derails at 3 inches, which suggests that the 10 percent minimum wheel load criterion may not be a good predictor of impending derailment. All other wavelengths are above 40 percent.

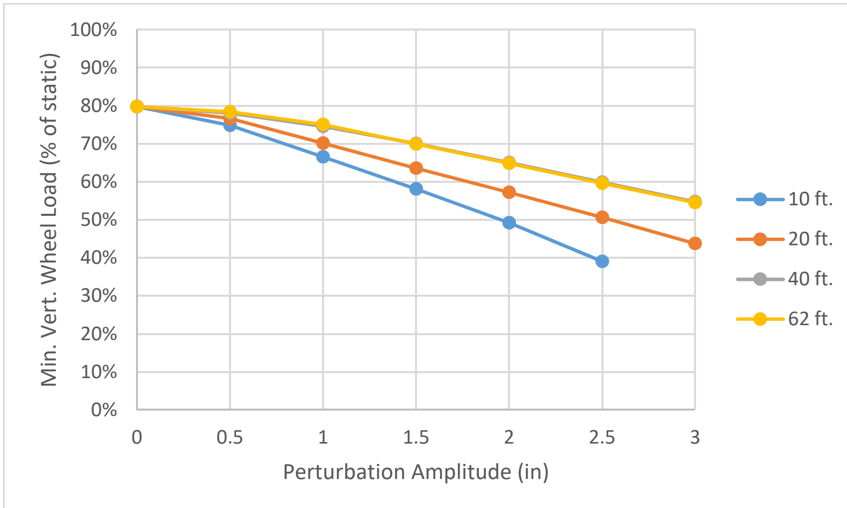

Figure 68. Low Speed Safety Advisory, Radial Arm, Bi-Level Car, Minimum Vertical Wheel Load

Figure 69 shows the wheel L/V ratio results of the single-level car for the rubber chevron truck design. These are slightly different results than for the other truck designs in that the simulation results show predicted derailment at 2.5 inches for the 10-foot wavelength, but at 2.0 inches for the 20-foot wavelength. Derailment is also predicted for the 40-foot wavelength at 2.5 inches and at 3 inches for the 62-foot wavelength perturbation. The 10-foot wavelength perturbation for

3-foot and 5-foot L/V results are much lower than the 50 msec results, and show a drop to well below the limit at the 2.0-inch amplitude, which suggests that these criteria may be incorrect for predicting the derailment that occurs at the 2.5-inch amplitude.

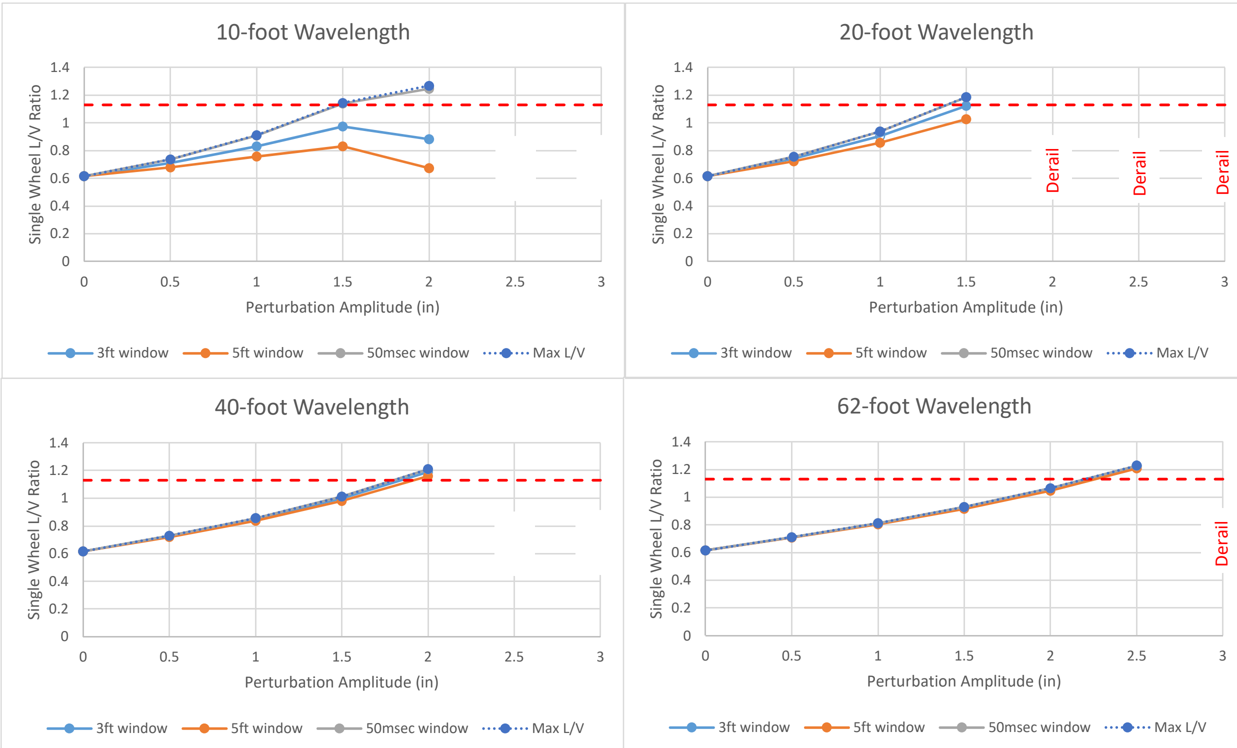

Figure 69. Low Speed Safety Advisory, Rubber Chevron, Single-Level Car, Single Wheel L/V Ratio

Figure 70 shows the minimum vertical wheel load results for the rubber chevron truck for the single-level car. The results show the rubber chevron generates the lowest vertical wheel load of about 25 percent of static load at 2-inch amplitude. Derailment was predicted for all wavelength perturbations, which suggests that the 10 percent minimum wheel load criterion may not be a good predictor of impending flange climb derailment.

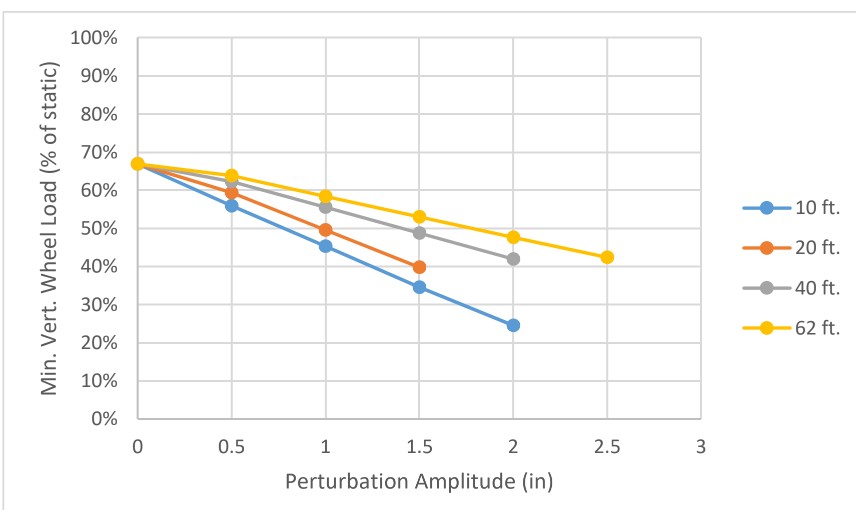

Figure 70. Low Speed Safety Advisory, Rubber Chevron, Single-Level Car, Minimum Vertical Wheel Load

Figure 71 shows the bi-level car results of wheel L/V ratio for the rubber chevron design truck. The results show predicted derailment at the 3-inch amplitude on the 10-foot wavelength case. The Nadal limit is exceeded at 2.5 inches on both the 10-foot and 20-foot wavelength perturbations. The 10-foot wavelength perturbation for the 3-foot and 5-foot L/V results are much lower than the 50 msec results, and below the limit at the 2.5-inch amplitude, which suggests that these criteria may be incorrect for predicting the derailment that occurs at the 3.0-inch amplitude.

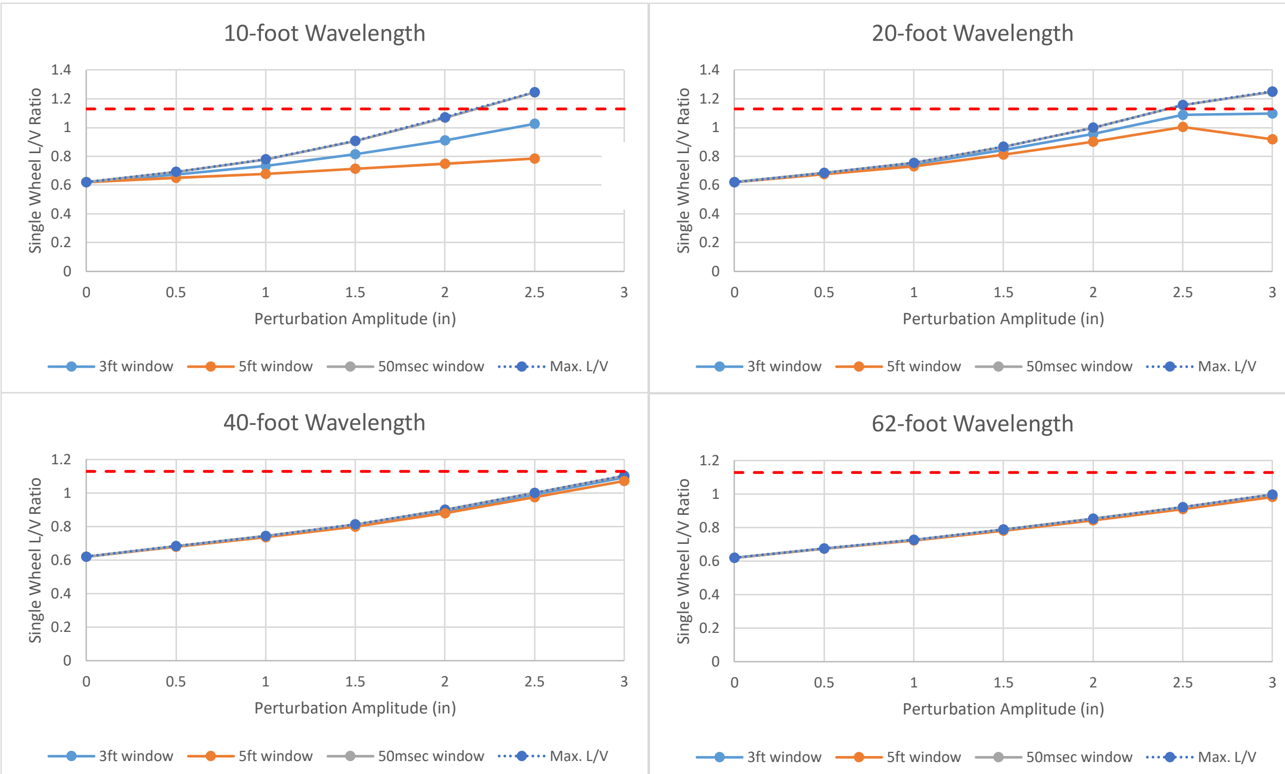

Figure 71. Low Speed Safety Advisory, Rubber Chevron, Bi-Level Car, Single Wheel L/V Ratio

Figure 72 shows the minimum vertical wheel load results for the bi-level car with the rubber chevron design trucks. The results show a minimum vertical wheel load for the 10-foot wavelength just above 30 percent at 2.5 inches and at 30 percent for the 20-foot wavelength at 3 inches. Derailment was predicted at the10-foot wavelength, which suggests that the 10 percent minimum wheel load criterion may not be a good predictor of impending derailment.

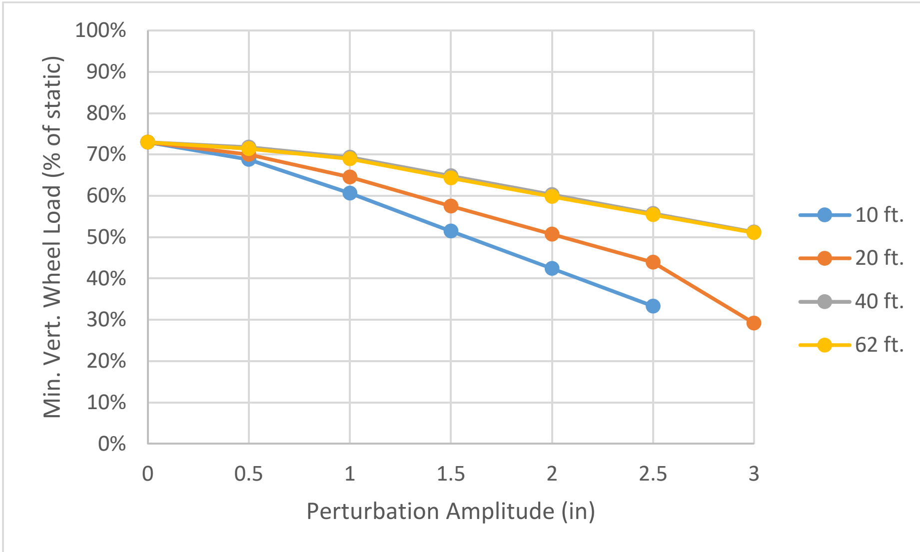

Figure 72. Low Speed Safety Advisory, Rubber Chevron, Bi-Level Car, Minimum Vertical Wheel Load

4. Quantifying the Load Environment and Predicted Wear

The operating environment directly affects the performance of railroad vehicles and accurate knowledge of the load environment is necessary for estimating truck component life expectancy. Conversely, the suspension design of vehicles along with load, both unsprung and sprung, contributes to the wear and tear of the track and infrastructure.

The current U.S. practice includes analyzing available data such as track loading data from Truck Performance Detectors and Wheel Impact Load Detectors, track geometry data from a measurement car, or instrumented wheelset (IWS) data. These practices may produce only a limited view of the load environment. International standards are being developed to address measurement of the loading environment.

Simulations were run to examine what range and distribution of loads might be expected given passenger trucks of varying design, albeit generic, along with a small sampling of freight type vehicles. In addition to the two car types with five different passenger truck designs, simulations for the following freight vehicles were also conducted:

- Auto Rack Car (4-axle vehicle)
- Loaded Hopper Car (4-axle vehicle)
- Double Stack Car (12-axle articulated car)

The static wheel load of the vehicle and/or truck will have a large influence on the overall load environment. Table 36 lists the static wheel loads for the passenger and freight vehicles and/or trucks simulated.

Table 36. Static Wheel Loads

Vehicle/Truck Type	Bi-Level (lb.)	Single-Level (lb.)
Conical Spring	16,912	11,162
Equalizer Beam	18,885	13,134
Journal Spring	16,874	11,124
Radial Arm	18,084	12,333
Rubber Chevron	16,146	10,396
Auto Rack	16,125	
Double Stack (Loaded)	33,154	
Loaded Hopper	32,875	

TTCI requested and was supplied measured track geometry from selected anticipated shared corridors. FRA supplied measured track geometry data from its ATIP to serve as representative track inputs to this study (Table 37). As opposed to analyzing the entire route, TTCI chose a representative curve from each of the following routes:

- Atlanta, GA – Charlotte, NC
- Alton, IL – Joliet, IL
- North Portland, OR – Eavan, WA

Table 37. Speed Matrix (in mph)

	Cant Deficiency (Inches)			
	-1	0	3	6
Curvature (degree)	Operating speed (mph)			
1.0	10.00	38.07	76.14	100.70
1.5	21.98	38.07	65.94	85.13
2.0	26.92	38.07	60.19	76.14
2.5	29.49	38.07	56.47	70.20
3.0	31.08	38.07	53.84	65.94
3.5	32.17	38.07	51.88	62.72
4.0	32.97	38.07	50.36	60.19

NUCARS® has the capacity to output a wear index, which is essentially the energy dissipated in the contact patch of the wheel and/or rail. This is calculated by multiplying the creep forces by the creepages. NUCARS® can generate this output as track-based output or from the wheel-based output. The data presented in the following section is from the track-based output, which has been normalized per axle, per unit of distance (feet) with the units of lb-in/in. Track wear indices from NUCARS® are output into left and right rail head wear and left and right gage face wear. The results presented in this section are the summed total of the gage face and head wear for each rail, i.e., high rail and low rail.

To limit the variables for this comparative analysis, the simulations were conducted using APTA 340 wheel profile and RE 136 lb rail profile. The profile used for the freight vehicles was the AAR-1B wide flange profile. Wheel-rail friction coefficients were assumed to be dry with a wheel-rail friction coefficient of $\mu = 0.5$. In actual operation, new wheels quickly wear to a worn shape that is more conformal to the rails, and the rails will also be worn, with the shape influenced by the degree of curvature, the worn shape of the wheels that run on them, and the maintenance (such as rail grinding) and lubrication practices of the particular railroad. These worn shapes and the local friction conditions can have a significant effect on the vehicle curving performance and the wear indices at a particular location.

It is recommended that when actual vehicles are being evaluated for a particular route that actual representative conditions be used for the analyses including:

- Measured track geometry from the route
- Representative measured worn rail profiles for the route
- Representative worn wheel profiles
- Representative wheel-rail friction conditions from the route

In actual practice, it is likely that many more freight cars will operate over a given shared corridor than passenger cars. Therefore, results should also be convolved with expected passenger and freight tonnage for the particular route to establish the cumulative predicted load environment and wear effects from each service.

4.1 Track Based Wear Index Results — Atlanta-to-Charlotte Irregularities

Figure 73 shows the wear index results for the single-level car for all five passenger truck designs with track irregularities from the Atlanta-to-Charlotte route. Plots are shown for three levels of cant deficiency and for high and low rail. The figure shows the wear index increases as a function of increased curvature. The results also show that the equalizer beam design generates more wear compared to the other designs, with the radial arm and journal spring designs generating the next highest wear. The conical spring design generates the lowest predicted wear trend. There is little difference of predicted wear as a function of cant deficiency, but a notable difference of predicted wear between high and low rail, with the high rail showing more wear. These differences are likely due to the high longitudinal stiffness of the equalizer beam primary suspension. The shorter axle spacing of the conical spring truck (7.87 ft. versus 8.5 ft.) probably also contributes to its lower wear index. The shorter axle spacing would tend to improve steering and permit the truck to run with lower axle angles of attack.

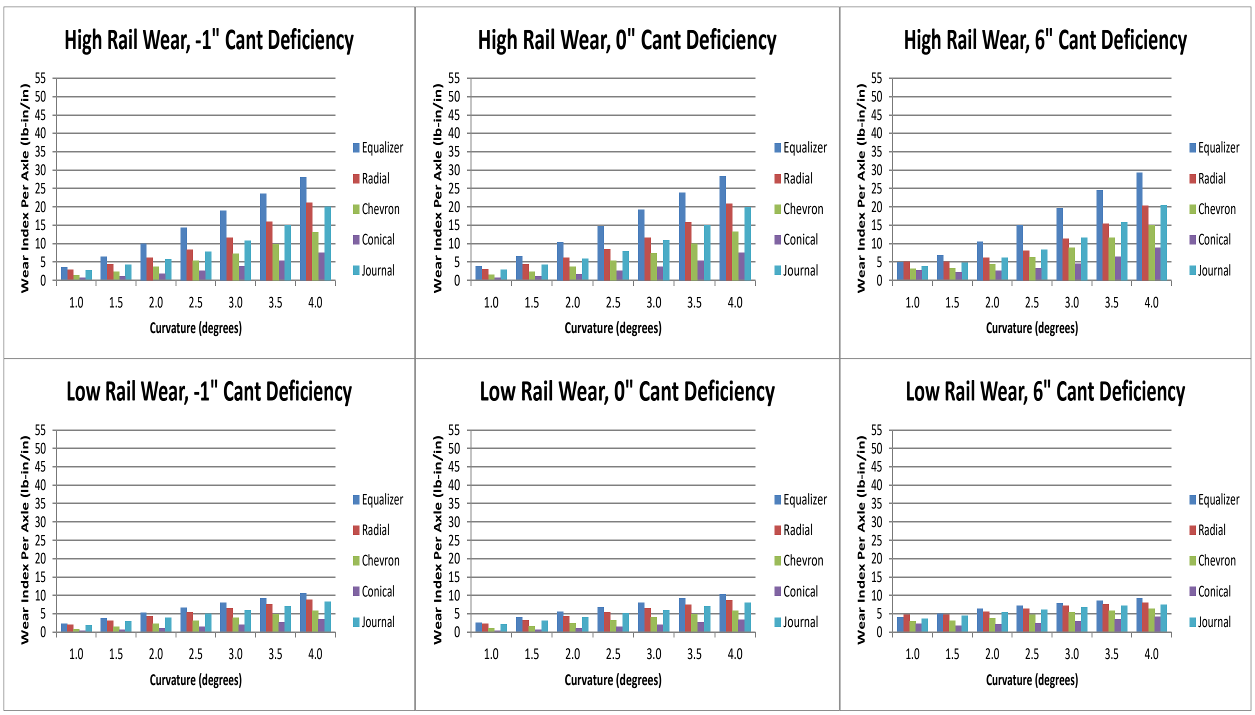

Figure 73. Wear Index Results, Atlanta-to-Charlotte Track Irregularities, Single-Level Car

Figure 74 shows the same wear index results, but for the heavier bi-level car. The wear trends are the same as those shown for the single-level car (Figure 73), but with higher wear index values, due primarily to the increase in wheel load.

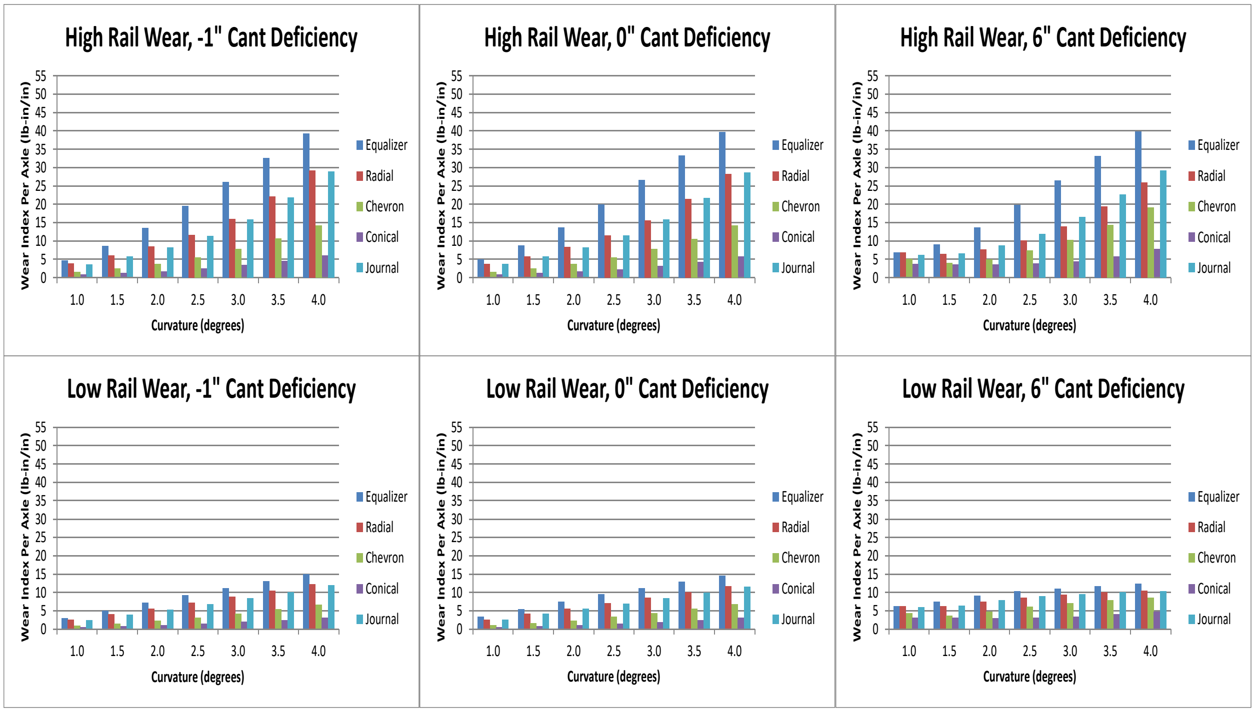

Figure 74. Wear Index Results, Atlanta-to-Charlotte Track Irregularities, Bi-Level Car

Figure 75 shows the freight car wear index results for the Atlanta-to-Charlotte track irregularities. Compared to the passenger car results shown in Figure 55 and Figure 56, the freight cars generate lower wear index values on the high rail than on the low rail. Similar to the passenger car results, the freight car results do not show a significant difference as a function of cant deficiency. There is also little difference between the three freight cars evaluated (i.e., an auto rack car, a double stack car, and a loaded hopper car).

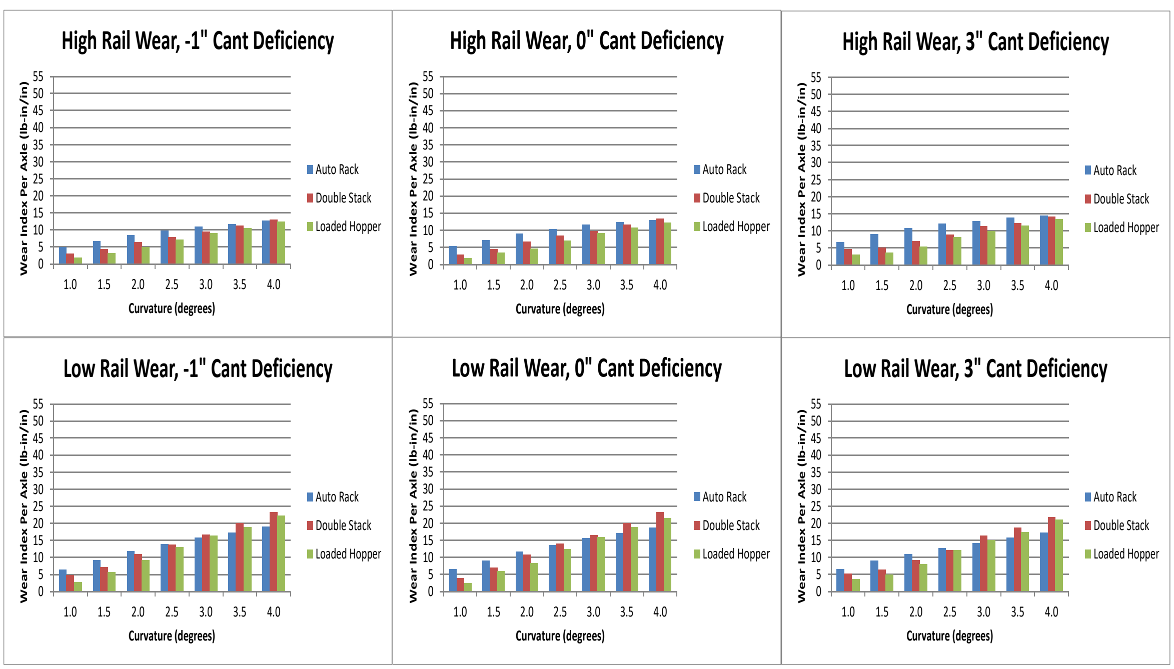

Figure 75. Wear Index Results, Atlanta-to-Charlotte Track Irregularities, Freight Cars

4.2 Track Based Wear Index Results — Alton, IL, to Joliet, IL, Track Irregularities

Figure 76 shows the wear index results for the single-level car for all five passenger truck designs with track irregularities from the Alton-to-Joliet route. These results show similar trends with the equalizer beam design generating much larger wear index results, especially on the high rail side. Again, there is virtually no difference in wear index values as a function of cant deficiency.

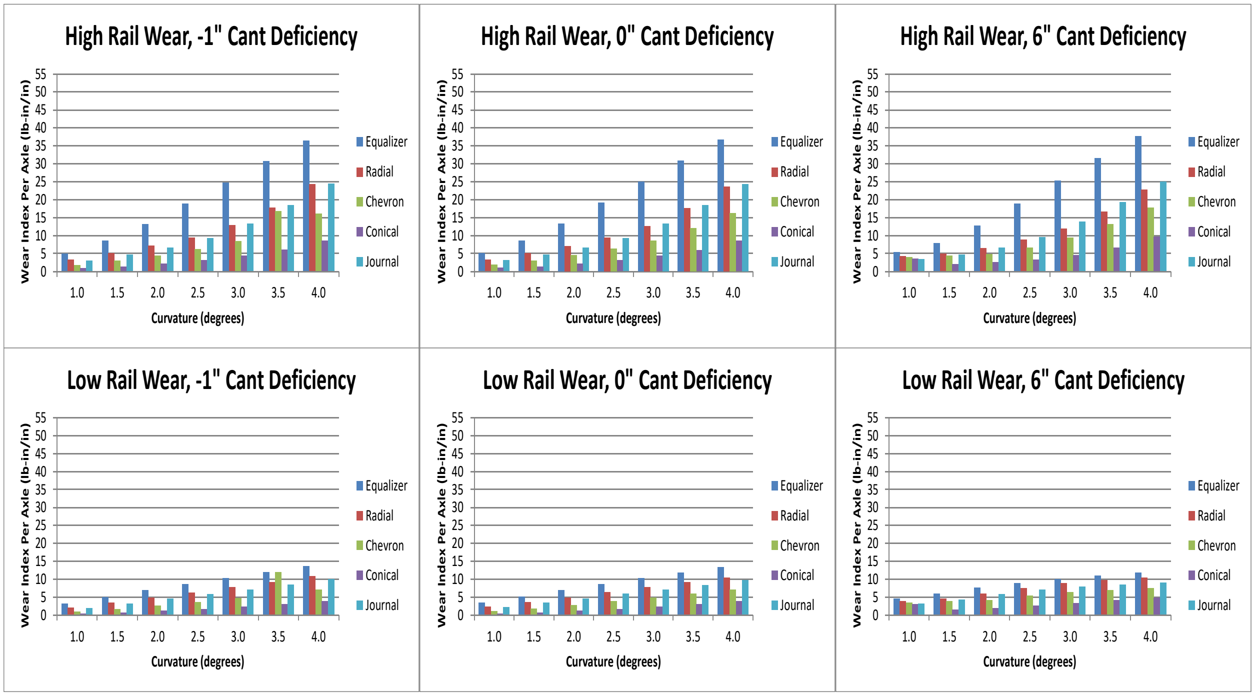

Figure 76. Wear Index Results, Alton-to-Joliet Track Irregularities, Single-Level Car

Figure 77 shows the wear index results for the heavier bi-level car for all five passenger truck designs with track irregularities from the Alton-to-Joliet route. The results show the same trend as those for the single-level car, but with higher wear index values due to the heavier wheel load.

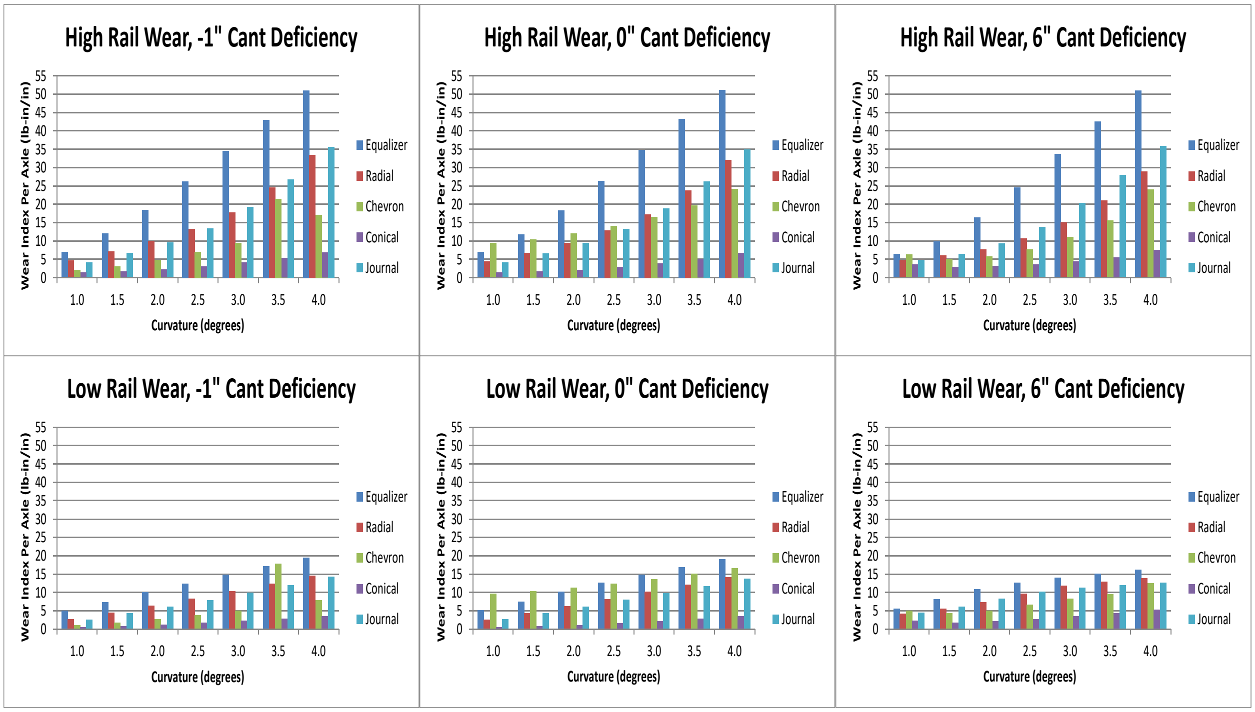

Figure 77. Wear Index Results, Alton-to-Joliet Track Irregularities, Bi-Level Car

Figure 78 shows the freight car wear index results for the Alton-to-Joliet track irregularities. The freight car results show larger wear index values on the low rail than on the high rail. There is little difference as a function of cant deficiency.

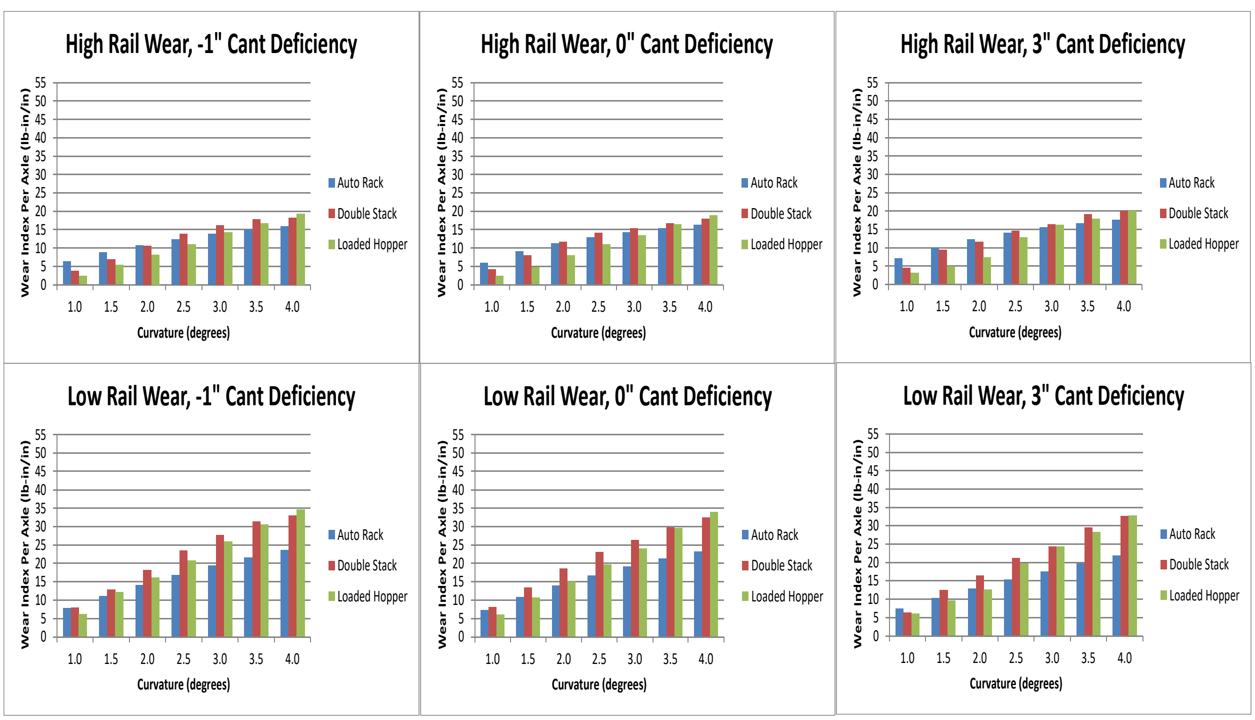

Figure 78. Wear Index Results, Alton-to-Joliet Track Irregularities, Freight Cars

4.3 Track Based Wear Index Results — Portland, OR, to Eavan, WA, Track Irregularities

Figure 79 shows the wear index results for the single-level car for all five passenger truck designs with track irregularities from the Portland-to-Eavan route. These results show similar trends with the equalizer beam design generating much larger wear index results, especially on the high rail side. Again, there is virtually no difference in wear index values as a function of cant deficiency. One other observation is that the track magnitude of these wear indices are smaller than those from the other track irregularities, which suggests an effect due to the local perturbations and the quality of the track may be a contributing factor. However, this is beyond the scope of this study, which is to provide a comparative analysis of various passenger truck designs.

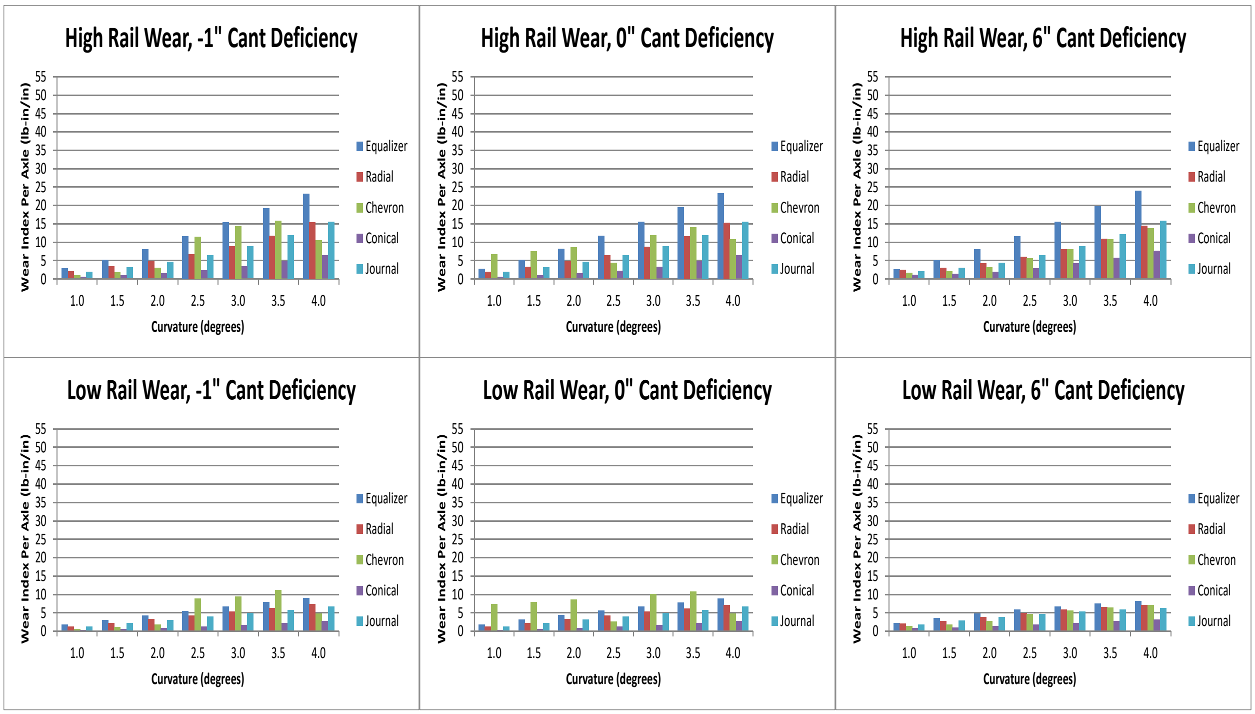

Figure 79. Wear Index Results, Portland-to-Eavan Track Irregularities, Single-Level Car

Figure 80 shows the wear index results for the heavier bi-level car for all five passenger truck designs with track irregularities from the Portland-to-Eavan route. The results show a similar trend as those for the single-level car, but with higher wear index values due to the heavier wheel load.

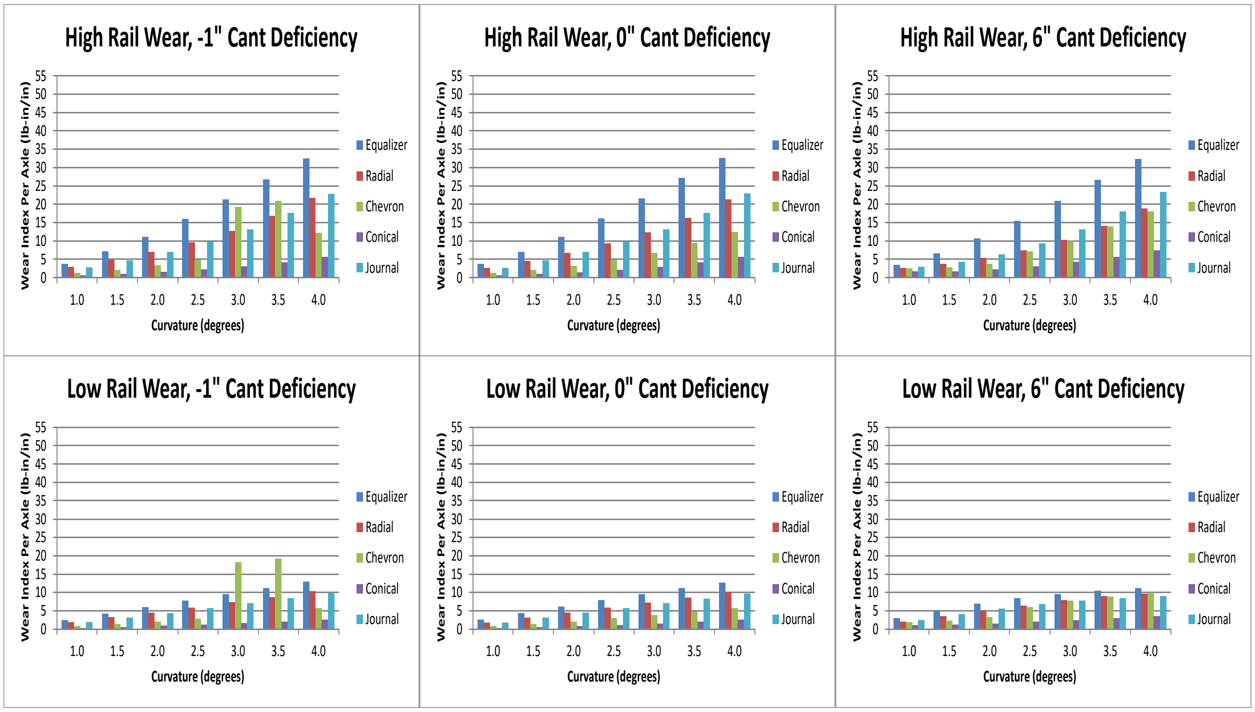

Figure 80. Wear Index Results, Portland-to-Eavan Track Irregularities, Bi-Level Car

Figure 81 shows the freight car wear index results for the Portland-to-Eavan track irregularities. The freight car results show larger wear index values on the low rail than on the high rail. There is little difference as a function of cant deficiency.

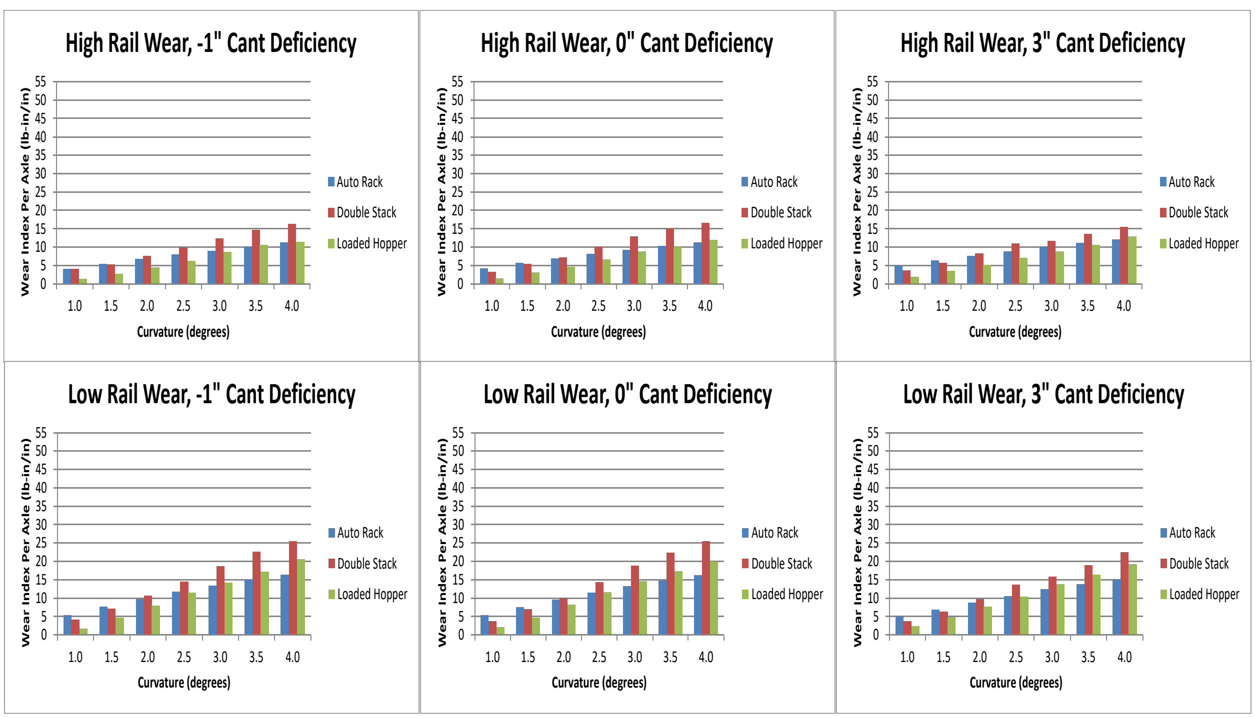

Figure 81. Wear Index Results, Portland-to-Eavan Track Irregularities, Freight Cars

4.4 Dynamic Forces Imparted on the Track

Heavy axle loads are known to impart more stress onto the track infrastructure because of increased load. Additionally, suspension design plays a key part in the amount of stress into the system. To examine the comparative dynamic performance of each design type in addition to the freight cars, vertical and lateral dynamic force distribution plots were generated. This was done by generating 5-kip load "bins" for the dynamic vertical loads and 2-kip load bins for the dynamic lateral forces. The load distributions were then normalized for the number of samples for the entire run. Figure 82 shows the dynamic vertical force distribution for all the cars, freight and bi-level, and plotted in the order of their dynamic force severity for the Atlanta-to-Charlotte track irregularities. The plot shows that the rubber chevron design generates the smallest vertical load distribution, followed by the auto rack freight car, the journal spring, the conical spring, the radial arm, and equalizer beam truck designs, with the loaded hopper and double stack freight cars generating the much higher dynamic vertical load inputs. The large difference is due in part to the much higher static axle loads of the loaded hopper car and double stack cars.

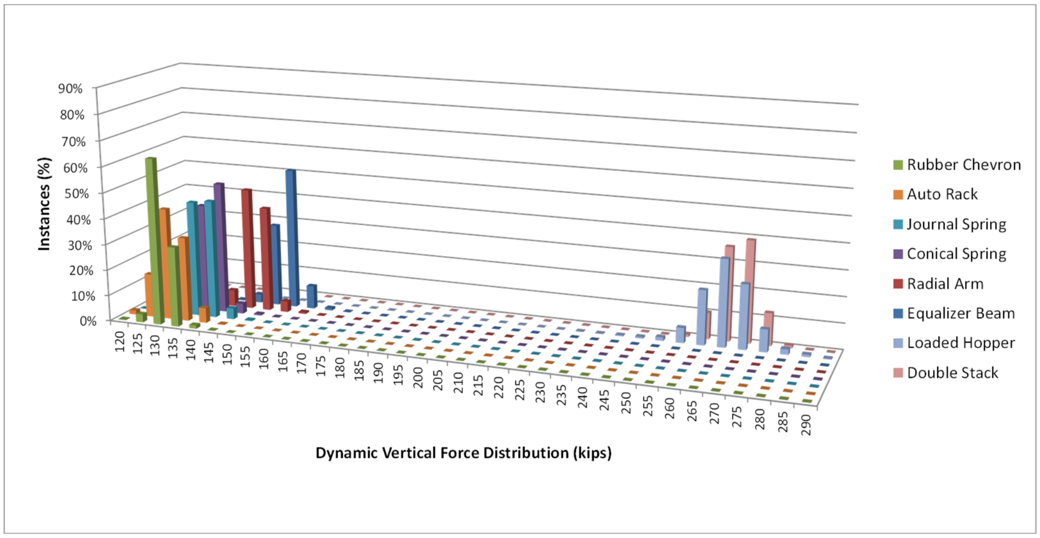

Figure 82. Vertical Force Histogram, Atlanta-to-Charlotte Track Irregularities

Figure 83 shows the dynamic lateral forces for the Atlanta-to Charlotte track irregularities. The loaded hopper and double stack freight cars generate larger dynamic lateral forces than the passenger truck designs, with the rubber chevron and conical spring truck designs producing the lowest forces. The low force results help explain the lower wear index results found for these two truck designs, and are likely due to the softer primary longitudinal and lateral suspensions of these two truck designs.

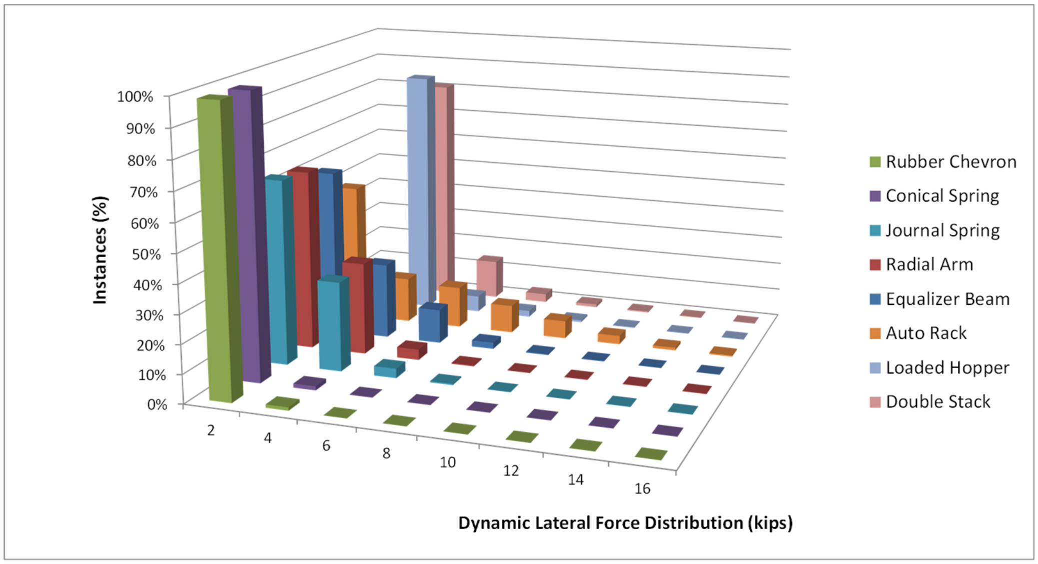

Figure 83. Lateral Force Histogram, Atlanta-to-Charlotte Track Irregularities

Figure 84 and Figure 85 show the results of the dynamic vertical and lateral forces from the irregularities from the Alton-to-Joliet route, respectively. These results trends are the same as those from the other routes.

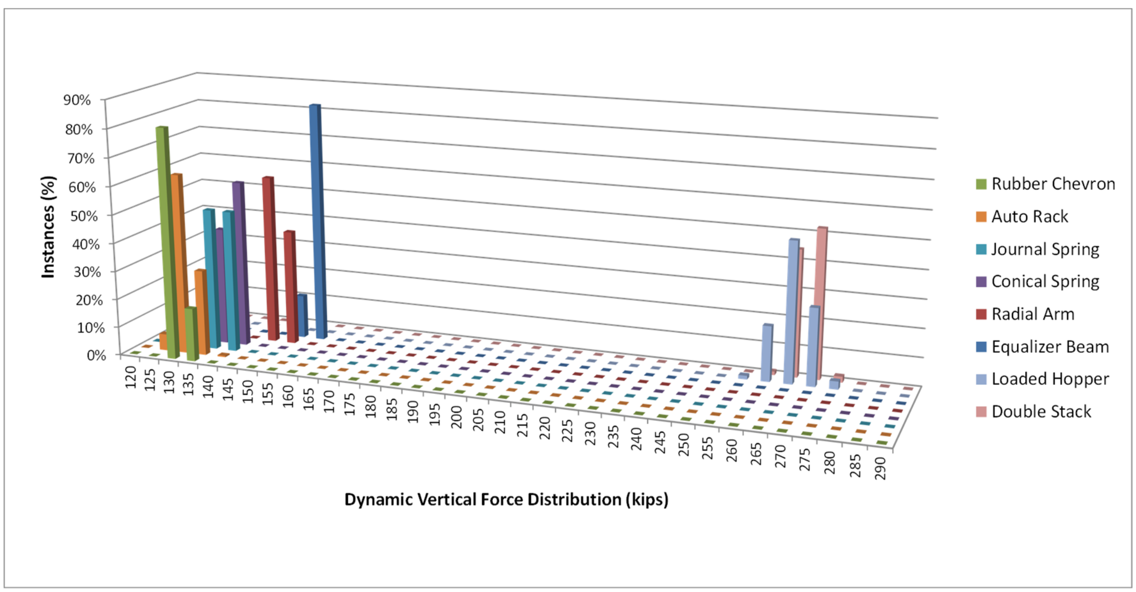

Figure 84. Vertical Force Histogram, Alton-to-Joliet Track Irregularities

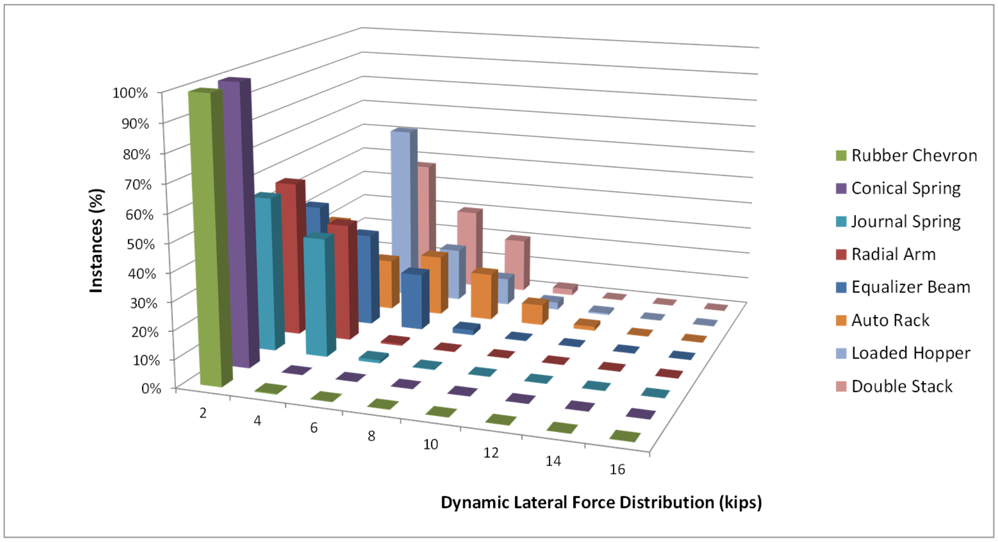

Figure 85. Lateral Force Histogram, Alton-to-Joliet Track Irregularities

Figure 86 and Figure 87 show the results of the dynamic vertical and lateral forces from the irregularities from the Portland-to-Eavan route, respectively. These results trends are the same as those from the other routes.

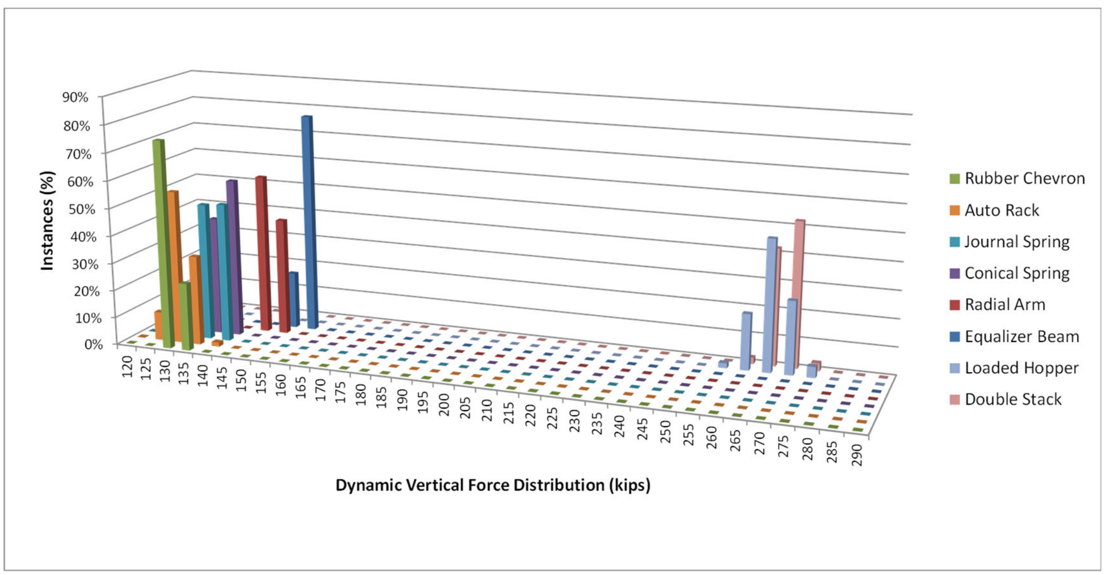

Figure 86. Vertical Force Histogram, Portland-to-Eavan Track Irregularities

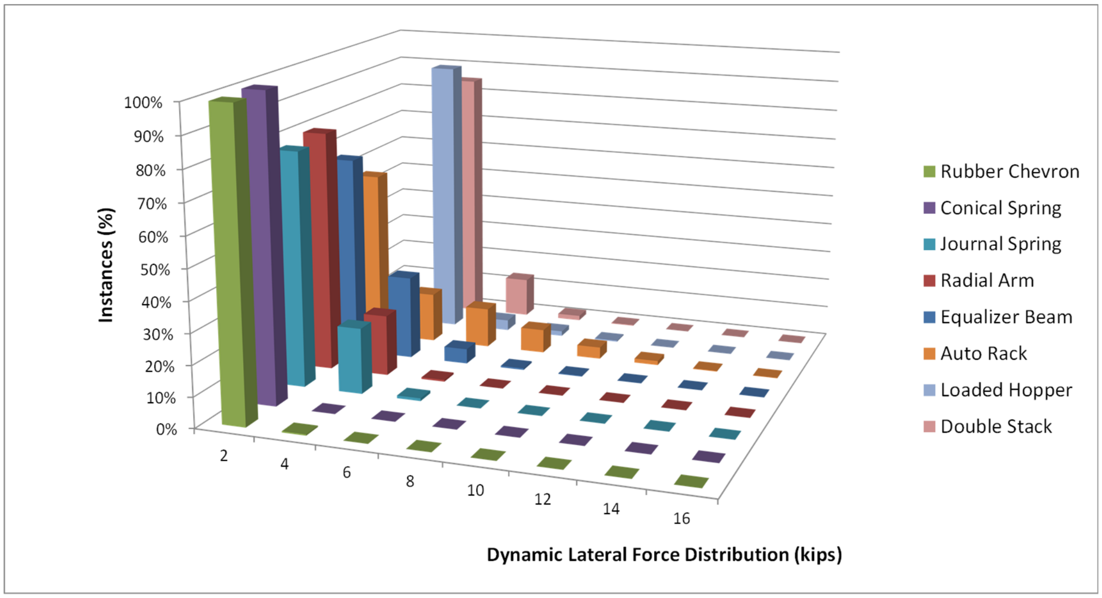

Figure 87. Lateral Force Histogram, Portland-to-Eavan Track Irregularities

4.5 Ride Quality Results

Although not directly related to safety performance, ride quality is an important aspect of passenger vehicle performance that is influenced by truck design. Ride quality was evaluated according to the International Organization for Standardization (ISO) 2631 [73]. Lateral, and vertical ride quality was analyzed separately for one arbitrary set of track irregularities for a range of curvatures. A 1-mile section of measured track was chosen from the Alton-to-Joliet track segment as representative track. The curvature channel and superelevation channel were then scaled such that a matrix for evaluating both wear and dynamic force inputs into the track on a common basis could be developed as a function of cant deficiency (speed).

The evaluation criteria used was the running root-mean-square (RMS) method. The running RMS method takes into account occasional shocks and transient vibration by use of a short integration time constant. The magnitude is defined as a maximum transient vibration value (MTVV).

It is important to note that ride quality analyses are somewhat subjective and can vary depending on changes in operating speed and are dependent on the quality of the track geometry. Table 38 describes the ISO 2631 ride quality index boundaries.

Table 38. ISO 2631 Ride Quality Index Boundaries

Vibration Magnitude (MTVV)	Comfort Level
aw<0.315	Not uncomfortable
0.315<aw<0.63	Little uncomfortable
0.5<aw<1	Fairly uncomfortable
0.8<aw<1.6	Uncomfortable
1.25<aw<2.5	Very uncomfortable

Ride quality results are presented for the selected 1-mile section of track for the range of curvatures evaluated for the load environment study. These results are intended to serve as comparative results and not as absolute as to whether or not the particular truck design or PRIIA vehicle type will provide a comfortable ride. This is especially important to note, because as was stated earlier, the secondary suspension used for this generic set of models would be designed as a system and tuned accordingly. A final note with respect to the limitation of these ride quality results is the fact that the main carbodies of the mathematical models are rigid masses and do not represent any bending or torsional flexibility of the carbody structure, which could heavily influence the ride quality. For the purpose of this comparison, results are presented for the leading, middle, and trailing sections of the carbody.

Figure 88 through Figure 90 show the lateral ride quality results for the leading, middle, and trailing ends of the carbody, respectively. The results show that ride quality improves as a function of curvature, although this could be directly related to the lower speeds in the sharper curves. The truck design comparison shows that the conical spring and the rubber chevron generate the highest levels of discomfort, whereas the equalizer beam, radial arm, and journal spring designs show a much more comfortable ride.

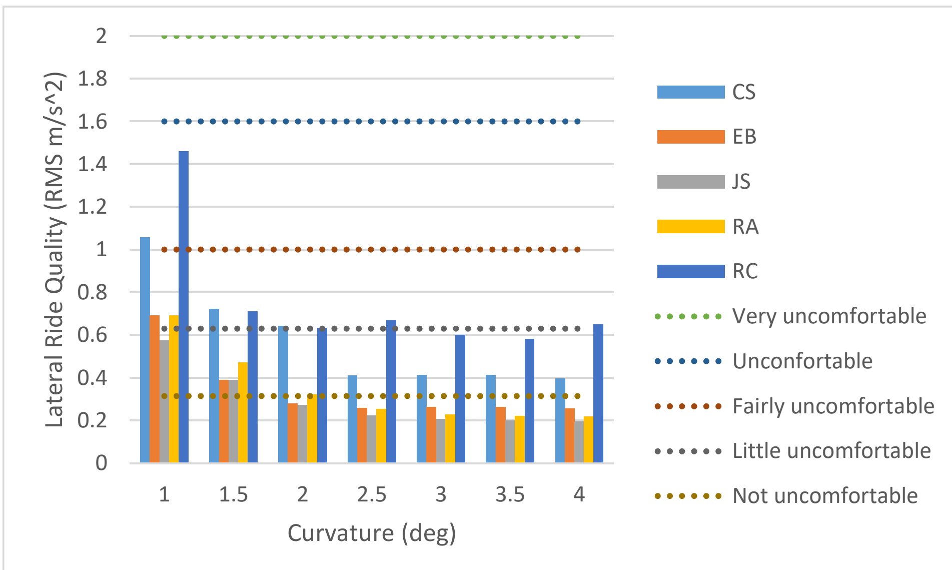

Figure 88. Lateral Ride Quality, Leading End of Car

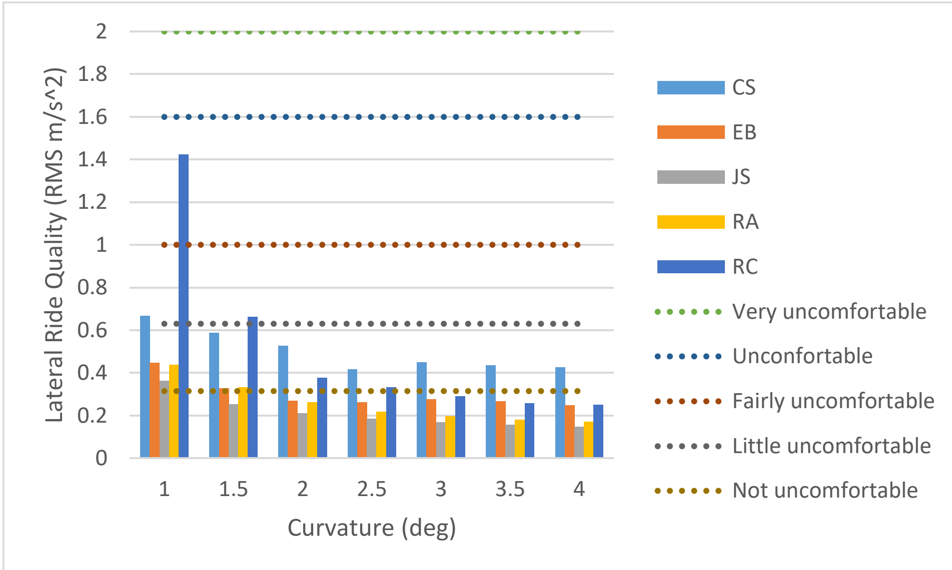

Figure 89. Lateral Ride Quality, Middle of Car

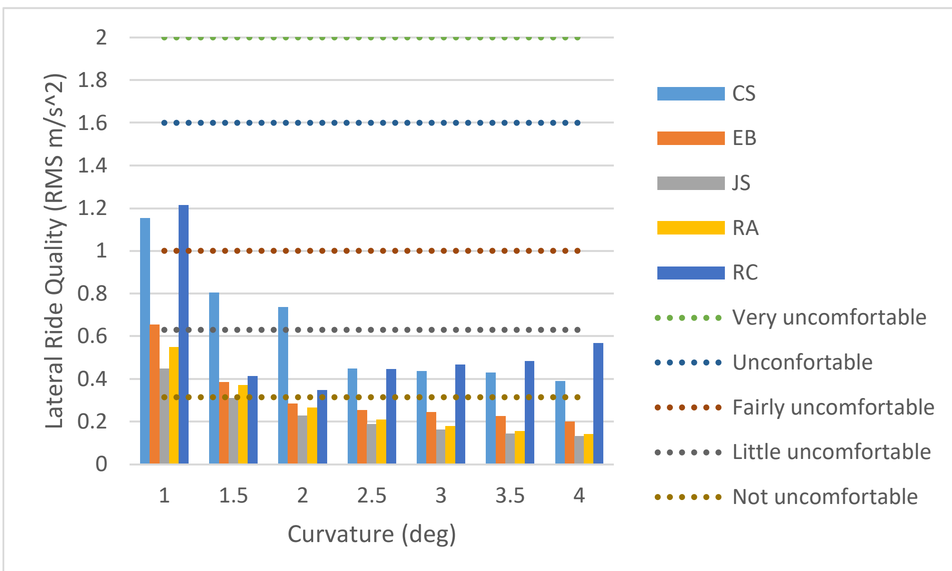

Figure 90. Lateral Ride Quality, Trailing End of Car

Figure 91 through Figure 93 show the vertical ride quality results for the leading, middle, and trailing ends of the carbody, respectively. The results show all results below the lowest limit. However, as was stated earlier, these models do not include any carbody bending flexibility, which could affect the ride quality results. The results also show that although the values are small, the rubber chevron appears to have the highest values.

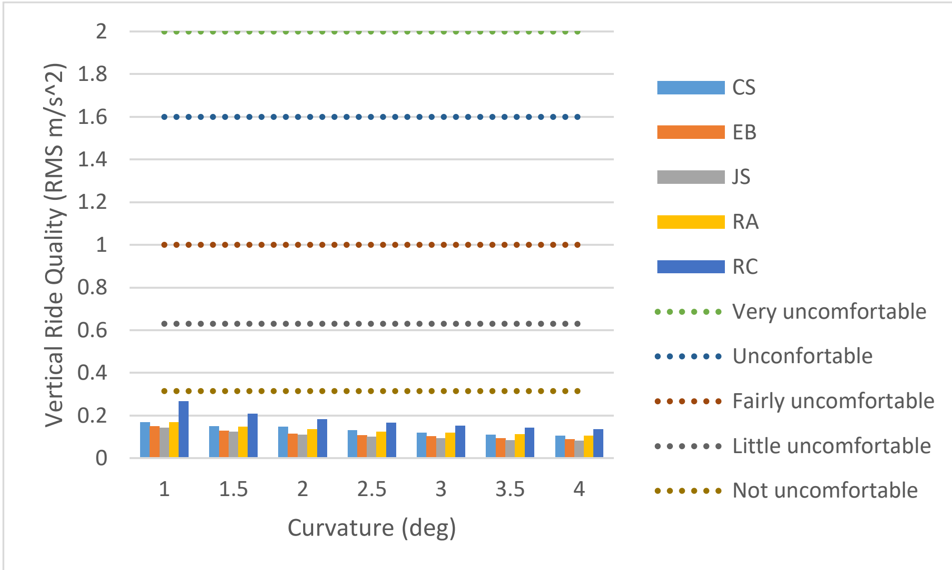

Figure 91. Vertical Ride Quality, Leading End of Car

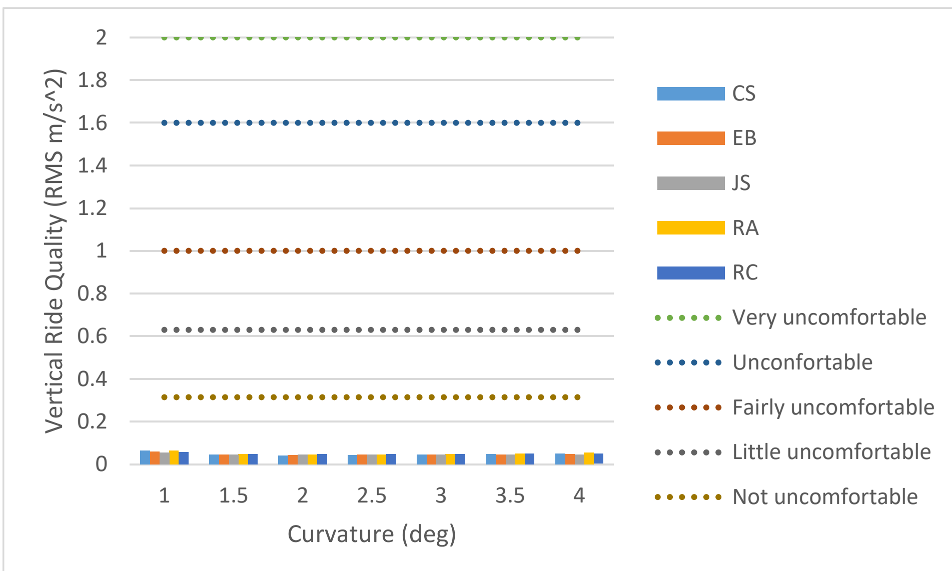

Figure 92. Vertical Ride Quality, Middle of Car

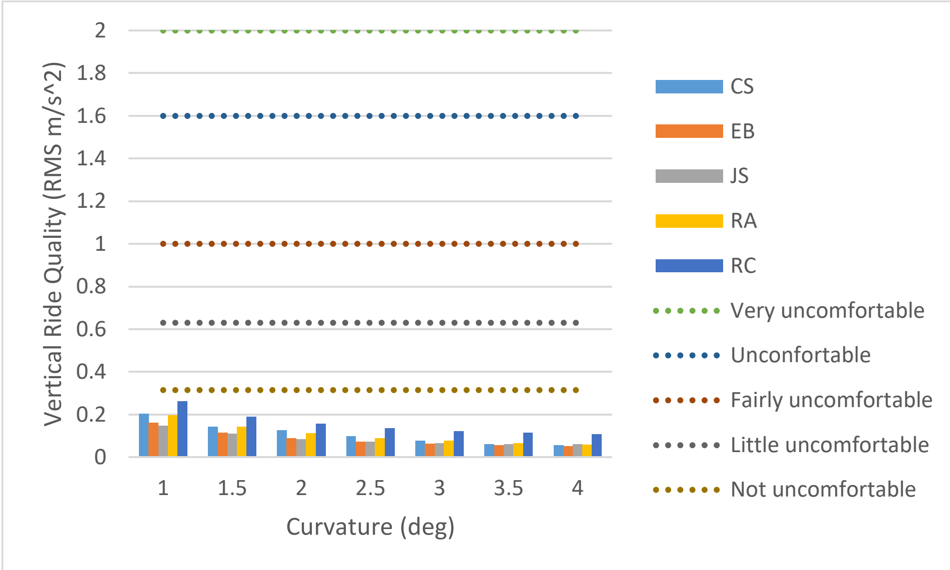

Figure 93. Vertical Ride Quality, Trailing End of Car

5. Validation Test Matrix

5.1 Analysis and Testing Requirements

A number of analysis and testing requirements must be met in order to qualify a vehicle for high-speed operation. The following subsections identify commonly used analysis and testing requirements, recommended practices, and procedures to demonstrate acceptable vehicle-track dynamic interaction performance for high-speed passenger vehicles:

- 49 CFR Part 213, Subpart G–Train Operation at Track Classes 6 and Higher [74]:
    - § 213.345–Vehicle/track system qualification
    - Appendix D–Minimally Compliant Analytic Track (MCAT) Simulations Used for Qualifying Vehicles To Operate at High Speeds and at High Cant Deficiencies
- 49 CFR § 213.329–Curves; elevation and speed limitations:
- 78 FR 16358–FRA Safety Advisory 2013-02, Low-Speed, Wheel Climb Derailments of Passenger Equipment With "Stiff" Suspension Systems [66]
- APTA PR-M-S-014-06, Standard for Wheel Load Equalization of Passenger Railroad Rolling Stock [68]
- Tests to validate the computer model simulations required by 49 CFR Part 213, Subpart G, § 213.345, and Appendix D
    - Vehicle characterization tests
    - On-track tests

Figure 94 summarizes the 49 CFR § 213.345 simulation and test requirements. Note that 49 CFR § 213.345 does not specify analyses and tests for operation below 90 mph (145 km/h). However, most high-speed passenger vehicles will also be required to operate safely at lower speeds on Track Classes 5 and less. Therefore, analyses and tests are recommended to address the evaluation of performance at lower speeds on lower classes of track as well. Although not required by FRA, these lower speed analyses and tests are frequently required by at least one of the following:

- Vehicle design specification
- State and local regulations
- Vehicle owner and/or operator

Example modeling and testing matrices for the recommended analyses and tests are included in the final subsections.

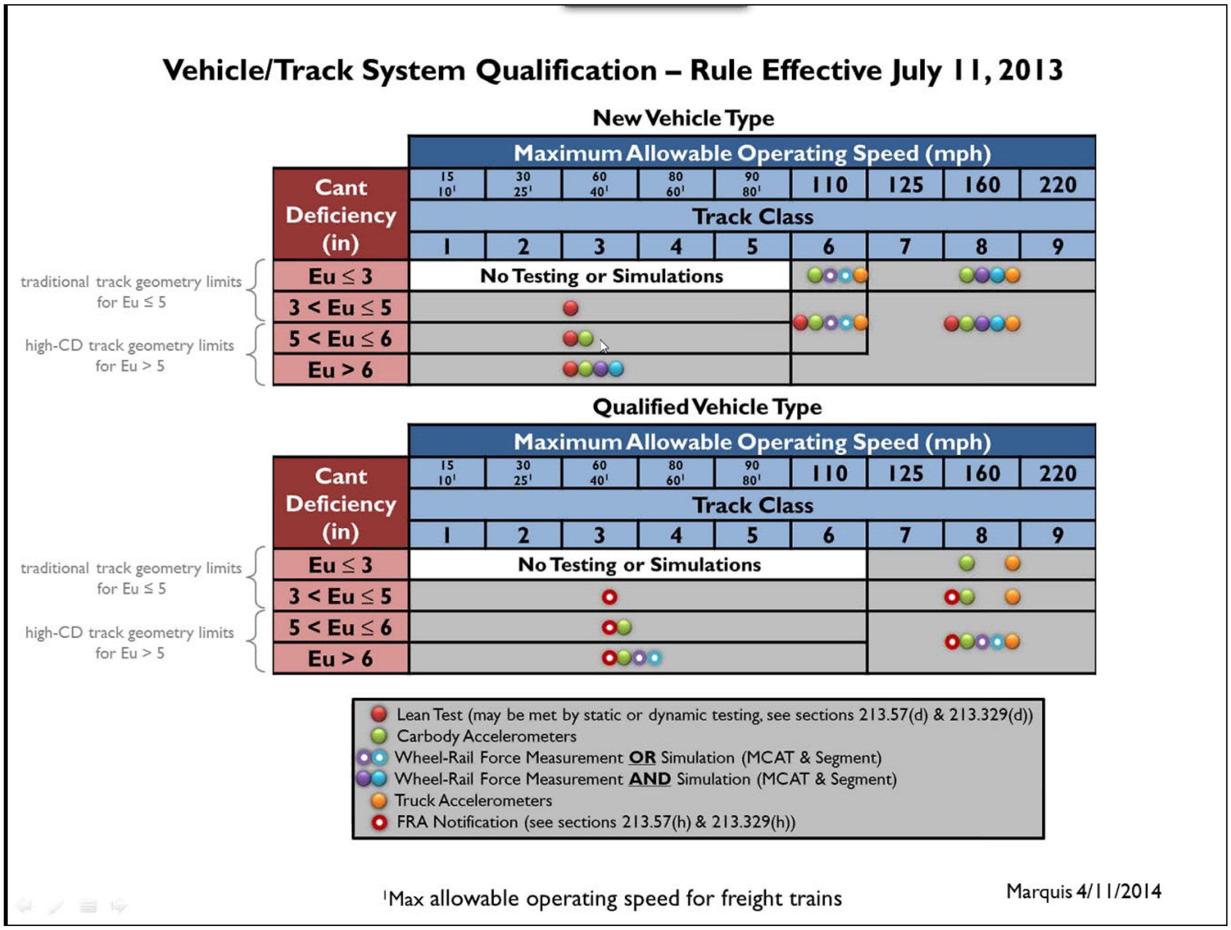

Figure 94. Summary of FRA High-Speed Passenger Vehicle Qualification Simulation and Test Requirements

Other analyses and tests may also be required for vehicle acceptance before entering service, but they are not included here as they do not pertain directly to vehicle-track interaction. These analyses and tests may include, but are not limited to:

- Passenger Ride Quality Analysis and Tests
- Carbody Structural Fatigue Analysis and Tests
- Carbody Crash Energy Management Analysis and Tests
- Brake Component and System Tests
- Braking Performance Tests
- Cab Control Tests
- Positive Train Control Tests
- Hot Bearing Detection
- Individual Car Component Tests
- Durability Tests

Comprehensive lists of passenger vehicle test recommendations and requirements, including those listed above, have been developed for the Federal Transit Administration [74], and are available in the Passenger Equipment Qualification Database.

5.2 Vehicle Characterization

To validate computer simulation models, characterization tests are recommended to ensure inputs to the models are accurate. Recent research conducted by TTCI for FRA [76] have recommended the following tests and demonstrated their effectiveness:

- Quasi-static vehicle characterizations to measure stiffness and damping properties of assembled vehicles
- Suspension component tests to measure stiffness and damping properties of individual spring and dampers
- Dynamic characterization tests to measure resonant frequencies of trucks and assembled vehicles and identify vehicle inertial properties and center of gravity locations

5.2.1 Quasi-static Vehicle Characterization

Rail vehicle suspensions can be complex, and the interaction of the different components as a system frequently result in system characteristics that are somewhat different than the individual components alone. To provide accurate input to computer models and to verify that the stiffness and damping characteristics of components match the intended values, quasi-static system tests are conducted to measure system properties such as: truck rotational resistance, overall stiffness, overall damping, gap and bump stop clearances, and other critical dimensions.

Truck resistive torque to measure turning resistance of the truck. For traditional truck trucks this test focuses on measurement of the rotational friction due to the side bearings and or centerplate. Many newer designs now use bolsterless trucks in which truck rotation is resisted by shear of the secondary suspension, in which case the test measures effective rotational stiffness. The methods for conducting the truck resistive torque tests are described in Section 3.6 of Ketchum, Fries, Wilson (2012). Truck resistive torque measurement methodology includes the calculation of a Truck Swivel Index, which is similar to some commonly used measures of low speed vehicle-track interaction performance to evaluate the ability of a truck to rotate in sharp turns [77].

Suspension system characterization tests to measure overall system stiffness and damping. The methods for conducting vertical and lateral quasi-static suspension characterization tests are described in Section 3.2 of Ketchum, Fries, Wilson (2012). These tests are particularly important for quantifying the nonlinear frequency dependent response of air springs in both vertical and shear directions. The quasi-static tests allow measurement of the very low frequency response, whereas the resonance tests allow verification response at higher frequencies.

Measurement of bump stop clearances, gaps, and other critical suspension dimensions. Bump stop clearances and other gaps can have a significant effect on vehicle dynamic response. Actual clearances and dimensions sometimes vary from design information. Measurements need to be made to ensure accurate input to models and verify that the system meets specifications. The methods for making such measurements on a typical passenger vehicle are described in Ketchum, Fries, Wilson (2012).

To provide accurate input to computer models and to verify that the stiffness and damping characteristics of components match the intended values, component tests are recommended to measure their properties such as stiffness and damping. For example, the stiffness of springs and damping rates of dampers can be measured in a load frame. The methods for conducting such tests for a typical passenger car spring and hydraulic damper are described in Sections 3.4 and 3.5 of Ketchum, Fries, Wilson (2012).

5.2.2 Dynamic Characterization

Resonance tests are conducted to measure system resonant frequencies. Data from these tests is used to help identify:

- Dynamic stiffness and damping characteristics of the assembled suspension and particular components. These tests are particularly important for quantifying the non-linear frequency dependent response of air springs in both vertical and shear directions. The quasi-static tests (Section 5.2.1) allow measurement of the very low frequency response, while the resonance tests allow verification response at higher frequencies.
- Carbody moments of inertial and center-of-gravity height
- Truck moments of inertial and center-of-gravity height

The carbody tests can sometimes be performed using manual excitation, or by jacking and suddenly releasing the car. The methods for conducting these tests are described in Section 3.1 Ketchum, Fries, Wilson (2012).

The truck tests are usually performed using an instrumented hammer to excite the truck resonant response. The methods for conducting the hammer tests are described in Section 3.3 of Ketchum, Fries, Wilson (2012).

5.3 Wheel Load Equalization Analyses and Tests

Wheel load equalization analyses and tests are commonly required by many vehicle specifications as a method to demonstrate acceptable performance on lower classes of track (below FRA Class 6). A commonly used specification for these analyses and tests is APTA

PR-M-S-014-06 (static wheel load equalization). The methods for conducting these tests are described in Section 3.3 of Ketchum, Fries, Wilson (2012). Pre-test simulations are recommended to identify and correct any potential performance issues before the tests begin. Results of these simulations can also subsequently be compared to the test results to aid in model validation.

5.4 Static Lean Tests

FRA requires performance of static leans test to ensure safe operation at high cant deficiency. The test requirements are defined in 49 CFR § 213.329.

5.5 Analyses and On-Track Tests at a Qualified Test Facility

The following subsections describe two types of analyses and on-track tests that are typically performed at a qualified test facility, such as the TTC:

- Tests to evaluate low speed vehicle-track interaction performance and provide data to help validate the computer simulation models
- Stage one vehicle qualification tests as required by 49 CFR § 213.345(f)(1)

To limit the scope of testing, pre-test modeling results should be used to help define the testing matrix and identify the regimes with the most critical performance to be included in the test matrix. The final testing matrix should include the regimes that will:

- Provide the best information for model validation
- Measure the most critical vehicle-track interaction dynamic response

5.5.1 Low Speed Performance and Model Validation

49 CFR § 213.345 does not specify analyses and tests for operation below 90 mph (145 km/h). However, most high-speed passenger vehicles will also be required to operate safely at lower speeds on Track Classes 5 and less. Therefore, this subsection describes analyses (computer modeling) and tests that are often used to address evaluation of performance at lower speeds on lower classes of track.

- Evaluation of vehicle-track interaction performance on-track classes below Track Class 5
- Validation of the vehicle models used in the computer simulations required by 49 CFR § 213.345

The following list of analyses and test regimes has been adapted from those successfully used for many years for the evaluation of freight vehicle performance according the AAR's Chapter 11 standards, and other commonly used analysis regimes [2]. These are often successfully used to demonstrate model validity and acceptable performance at speeds below 90 mph (145 km/h) for passenger vehicles. Analyses and tests include the several regimes that are described in Section 5 of AAR's Chapter 11 MSRP (the specific subsection is in parentheses) [2]:

- AAR Chapter 11 Paragraph 11.8.2 Twist and Roll (Section 5.5.1)
- AAR Chapter 11 Paragraph 11.8.3 Pitch and Bounce (Section 5.5.2)
- AAR Chapter 11 Paragraph 11.8.4 Yaw and sway (Section 5.5.3)
- AAR Chapter 11 Paragraph 11.8.5 Dynamic Curving (Section 5.5.4)
- AAR Chapter 11 Paragraph 11.7.3 Operation In Constant Curves (Section 5.6)
- AAR Chapter 11 Paragraph 11.7.4 Spiral Negotiation (Section 5.6)
- Evaluation of low speed vehicle-track interaction performance to address the FRA low speed safety advisory [66]. The referenced example shows analyses and tests on a 12-degree curve with a severe dip in the outside rail and a No. 8 turnout (see Section 5.6 of AAR Chapter 11 Paragraph 11.7.4 Spiral Negotiation). Some recent vehicle specifications have also required analyses and tests over specific turnouts and crossovers with dips and bumps in the closure curves.
- Evaluation of dynamic response to track perturbations at wavelengths specific to vehicle dimensions such as:

  - Dips in one rail at twice the axle spacing in a truck
- Cross level and alignment variations at track center spacing
- These are frequently required by vehicle design specifications
- Figure 95 and Figure 96 shows a special 500-foot long tangent track section known as the High-Speed Adjustable Perturbation Slab (HS-APS) at the TTC that was recently installed by FRA, which is designed to allow easy installation of such features [78].

Figure 95. 500-foot Long HS-APS Test Track at the TTC

Figure 96. Close-up View of HS-APS Test Track at the TTC

5.5.2 49 CFR § 213.345 Stage One Analyses and Tests

Title 49 CFR § 213.345(f)(1) requires that stage one vehicle qualification tests be conducted on segments of tangent and curved track that meet the minimum track class requirements of the intended route(s) where operations will exceed 90 mph (145 km/h).

Pre-test simulations using the measured track geometry of the stage one tangent and curved test segments are not required by 49 CFR § 213.345(f)(1). However, such pre-test simulations are recommended to identify and correct any potential performance issues before the tests begin. Results of these simulations can also subsequently be compared to the test results to aid in model validation. Simulations are typically performed for one load condition in speed increments of 5 or 10 mph (8 or 16 km/h), from 90 mph (145 km/h) to 5 mph (8 km/h) above the maximum intended operating speed.

Post-test modeling with the validated models can then be used to extend the range of on-track testing results.

5.6 Analysis and On-Track Tests Over Intended Route and MCAT

49 CFR § 213.345(f)(2) requires that stage two vehicle qualification tests be conducted on the intended route(s) where operations will exceed 90 mph (145 km/h). Pre-test simulations are required for the vehicle operating over measured track geometry of a track segment representative of the route, and over the MCAT required by 49 CFR § 213.345 Appendix D. Results of these simulations can also subsequently be compared to the test results to aid in model validation.

- Provide the best information for model validation
- Measure the most critical vehicle-track interaction dynamic response

Post-test modeling with the validated models can then be used to extend the range of on-track testing results.

For vehicles operating at Track Class 7 speeds or higher, the tests require use of IWS to measure the wheel-rail forces. IWS are optional for Track Class 6 if certain additional simulation requirements (including MCAT) are met. Additional instrumentation is required for all track classes to evaluate performance according to the safety performance criteria defined in 49 CFR § 213.333.

5.7 Example Modeling and Test Matrices

The following subsections provide example modeling and test matrices for evaluating the vehicle-track dynamic behavior of a hypothetical high-speed passenger vehicle with an air suspension. In practice, actual test matrices would need to be developed to address the particular vehicle requirements based on the following:

- Testing and analysis requirements in the vehicle design specification
- FRA requirements
- State and local requirements
- Owner/operator requirements
- Suspension design
- Engineering judgement

To limit the scope of testing, pre-test modeling should be used to help define the testing matrix and identify the regimes with the most critical performance to be included in the test matrix. The final testing matrix should include the following regimes that will:

- Provide the best information for model validation
- Measure the most critical vehicle-track interaction dynamic response

Post-test modeling with the validated models can then be used to extend the range of on-track testing results.

5.7.1 Example Modeling Matrix

Whenever possible, it is recommended that the pre-test analyses (modeling) be performed using measured track geometry and rail profile shapes from the actual test zones. A wheel-rail friction coefficient of $\mu = 0.5$ is recommended to represent likely worst-case friction conditions.

- Different load conditions, at a minimum empty (AW0) and fully loaded (AW2 or AW3 depending on the type of service)
- For three-point air suspensions, curving response and transient response can be different depending on which end is leading, so simulations should be run with A-end leading and B-end leading

- Likely component wear conditions (wear simulations are frequently required in vehicle design specifications) such as:
  - Air suspension inflated and deflated
  - Worn dampers
  - Worn wheels
  - Wide and narrow clearances
  - Increased friction at center plates, side bearings and pedestal jaws
  - Stiffer and softer polymer suspension bushings
  - The selection of wear conditions to simulate is dependent on:
    - Suspension design
    - Vehicle design specification requirements[2]
    - Engineering judgement

Recommended simulation regimes and vehicle conditions for a vehicle with air suspension include the following:

- Static lean, loaded and empty, air suspension inflated and deflated (Section 5.4)
- Static wheel unloading, loaded and empty, air suspension inflated and deflated (Section 5.3)
- Low speed performance, loaded and empty, air suspension inflated and deflated plus selected wear conditions (Section 5.5.1)
- High speed qualification (49 CFR § 213.345), loaded and empty, air suspension inflated and deflated plus selected wear conditions
  - Over measured track geometry for the qualified test facility (Section 5.5.2)
  - Over measured represented track geometry from the actual route (Section 5.6)
  - Over the required Appendix D MCAT perturbations (Section 5.6)

Results of the modeling will be used to identify the most important regimes and combinations of loading, air suspension, and wear conditions to include in the tests. Table 39 and Table 40 show example simulation matrices for quasi-static tests and track with and without perturbations. The corresponding test matrices are also included.

[2] Analyses of vehicle wear conditions are frequently required in vehicle design specifications.

Table 39. Example Simulation and Test Matrix for Passenger Car with Air Suspension: Quasi-Static Tests and Unperturbed Track Tests

Case	Dynamic condition	Load	Simulaions		Wheel condition		Speed		Track condition		Yaw damper condition		Vertical damper condition		Air spring condition		Comments
			Simulation	Testing	Simulation	Testing	Simulation	Testing	Simulation	Testing	Simulation	Testing	Simulation	Testing	Simulation	Testing	
1A	APTA SS-M-014006 Wheel Load Equalization	Empty	x	x	New	New	N.A.		Shop		New		New		Inflated/ Deflated	Inflated	
1B		Loaded	x		New												
3A	FRA 213.370 Static Lean	Empty	x		New		N.A.		Shop		New		New		Inflated/ Deflated		
3B		Loaded	x	x	New	New										Inflated	
4A	FRA 213.345 High Speed Qualification at Qualified test Facility (includes Hunting)	Empty	x	x	New/Worn	New/Worn	70 to 130mph 5mph increment		Tangent and 0.8 deg curve		New/ Degraded/ No	New	New/ Degraded	New	Inflated/ Deflated	Inflated	
4B		Loaded	x		New/Worn												
5A	FRA 213.345 High Speed Qualification on Actual Route(includes Hunting)	Empty	x	x	New/Worn	New	See comment		Actual Route		New/ Degraded	New	New/ Degraded	New	Inflated/ Deflated	Inflated	Maximum Speed profile, and Maximum Speed plus 5 mph, recommend pre-test modeling at lower speeds also.
5B		Loaded	x		New/Worn												
6A	Chapter 11 Constant Curving	Empty	x		New/Worn	New	12,24,32mph		7.5/10/12 deg -3/0/3 Unbalance		New/No	New	New		Inflated/ Deflated		Includes analysis of entry/exit spirals on all curves. Test should be done at whichever load condtion produces worst case response in pre-test modeling
6B		Loaded	x	x	New/Worn												
7A	Chapter 11 Spriral Negotiation	Empty	x		New/Worn	New	12 to 32 mph in 5 mph increments		Spiral geometry consistent with 6A/6B		New/No	New	New		Inflated/ Deflated		
7B		Loaded	x	x	New/Worn												

Table 40. Example Simulation and Test Matrix for Passenger Car with Air Suspension: Track with Perturbations

Case	Dynamic condition	Load	Simulaions		Wheel condition		Speed		Track condition		Yaw damper condition		Vertical damper condition		Air spring condition		Comments
			Simulation	Testing	Simulation	Testing	Simulation	Testing	Simulation	Testing	Simulation	Testing	Simulation	Testing	Simulation	Testing	
8A	Chapter 11 Twist/Roll	Empty	x		New/Worn		10 to 130mph 5mph increment				New		New		Inflated/ Deflated		Maximum test speed to be determined by maximum allowed by test track and test results
8B		Loaded	x	x	New/Worn	New							New/ Degraded	New		Inflated	
9A	Chapter 11 Pitch/Bounce	Empty	x		New/Worn		10 to 130mph 5mph increment				New		New		Inflated/ Deflated		Maximum test speed to be determined by maximum allowed by test track and test results
9B		Loaded	x	x	New/Worn	New							New/ Degraded	New		Inflated	
10A	Chapter 11 Yaw/Sway	Empty	x		New/Worn		10 to 130mph 5mph increment				New/No		New		Inflated/ Deflated		Maximum test speed to be determined by maximum allowed by test track and test results
10B		Loaded	x	x	New/Worn	New	10 to 105mph 5mph increment				New/No	New	New/ Degraded	New		Inflated	
11A	Chapter 11 Dynamic Curving	Empty	x		New/Worn		12 to 32mph				New		New		Inflated/ Deflated		
11B		Loaded	x	x	New/Worn	New										Inflated	
12A	No. 8 Turnout (FRA Low Speed Derail)	Empty	x	x	New/Worn	New	5 to 15 mph				New		New		Inflated/ Deflated		
12B		Loaded	x	x	New/Worn	New											
13A	12 Degree curve with single dip (FRA Low Speed Derail)	Empty	x	x	New/Worn	New	5 to 15 mph		2" dip in outsdie rail		New		New		Inflated/ Deflated		
13B		Loaded	x	x	New/Worn	New											
14A	FRA Appendix D MCATs	Empty	x	See comment	New/Worn	See comment	70 to 130mph 5mph increment		MCAT		New/ Degraded		New/ Degraded		Inflated/ Deflated		If simulation results show poor repsonse on a particular input, test on HS-APS with that perurbation
14B		Loaded	x	See comment	New/Worn	See comment					New/ Degraded		New/ Degraded				

5.7.2 Testing Matrix

Recommended testing includes both quasi-static testing and dynamic tests on track. To minimize the number of tests, the matrix of on-track dynamic tests is usually developed using the pre-test simulations results to help identify the most important regimes and combinations of loading, air suspension, and wear conditions to include in the tests.

Recommended test regimes and vehicle conditions for a vehicle with air suspension include the following:

- Vehicle characterization tests include:
  - Quasi-Static Vehicle Characterization (Section 5.2.1). These tests should include the measurement of the lateral and vertical quasi-static stiffness of the air suspension and the primary suspension. Tests should also be conducted with air suspension deflated to quantify the "safety spring." If the primary suspension has chevrons or other rubber/polymer components, these tests should include the measurement of the longitudinal stiffness. If the car has antiroll bars, roll stiffness tests should be performed with and without the antiroll bar connected. For vehicles with pedestal jaw type suspensions, the recommended clearances and gap measurements should include lateral and longitudinal clearance of the pedestal jaws to axle boxes at each axle box, as well as upper and lower limits on vertical travel.
  - Component Characterizations. Tests should include the measurement of the damper characteristics (damping rates and bushing stiffness) of each type of damper. Tests should also measure primary spring vertical and shear stiffnesses. Note that for radial arm suspension, these stiffnesses are expected to be different than stiffnesses measured during quasi-static and dynamic tests of the assembled vehicle.
  - Dynamic Characterization (Section 5.2.2). These tests should include measurement of the lateral and vertical dynamic stiffness and damping of the air suspension. Tests should also be conducted with air suspension deflated to quantify the effects of the safety spring.
- Static lean, loaded and empty, air suspension inflated and deflated (Section 5.4)
- Static wheel unloading, loaded and empty, air suspension inflated and deflated (Section 5.3)
- Tests at a qualified test facility
  - Low speed performance and model validation, loaded and empty, air suspension inflated and deflated plus selected wear conditions (Section 5.5.1)
  - High-speed qualification (49 CFR § 213.345), loaded and empty, air suspension inflated and deflated, plus selected wear conditions
- Tests over the actual route (Section 5.6)
- Tests over specific 49 CFR § 213.345, Appendix D MCAT perturbation(s) if the model results show poor response and indicate verification tests are required (Section 5.6) Table 39 and Table 40 show example test matrices for quasi-static tests and track with and without perturbations. The corresponding simulation matrices are also included. Results

of the testing should be used to validate the modeling and update the models. Post-test modeling using the updated models is recommended if significant adjustments to the models were required to validate the simulations.

Table 39 and Table 40 show example test matrices for quasi-static tests and track with and without perturbations. The corresponding simulation matrices are also included. Results of the testing should be used to validate the modeling and update the models. Post-test modeling using the updated models is recommended if significant adjustments to the models were required to validate the simulations.

6. Conclusion and Recommendations

6.1 General Recommendations and Conclusions

TTCI has conducted an evaluation of existing high-speed passenger truck designs for use in shared freight and passenger operations in North America up to 125 mph (201 km/h). High-speed, intercity, and commuter types of passenger equipment were evaluated, as distinct from heavy and light rail mass transit systems. The work performed included:

- Development of a matrix of existing high-speed truck designs
- Generic model development for five suspension types
- Simulations of dynamic response for a wide range of high and low speed operation conditions
- Quantifying the load environment
- Recommendations for simulation validation and test matrices

Test results indicate no single truck design stands out as having better overall performance than another. A truck that performs better than other designs in one regime often performs worse than the other designs in another regime. For example, the equalizer beam truck performed well in the wheel load equalization and low speed derailment analyses but also produced the highest wheel-rail wear results.

Because all the simulation and analyses were performed for hypothetical generic representative truck designs, none of the results and conclusions presented should be used to identify an individual truck design as being the best or worst for a particular performance regime or service application. Instead, the results should be used as a guide to understand the challenges and design trade-offs that must be met to develop a vehicle and suspension for operation on shared freight and passenger corridors with a wide range of track classes.

This work focused on locomotive hauled passenger cars, but did not include self-propelled cars (i.e., EMUs and DMUs) or locomotives. Future work could include similar analyses for these vehicles. However, from the experience of this project, it is unlikely that manufacturers of such vehicles will be likely to provide detailed information about their vehicle and suspension design parameters. Therefore, such a study would also be limited to simulating hypothetical generic representative designs.

The following subsections provide specific conclusions and recommendations from the four phases of work conducted by TTCI.

6.2 Matrix of High-Speed Truck Designs

TTCI conducted a survey to evaluate state of the art passenger vehicles and suspensions currently available in the North American, European, and Asian markets. The truck matrix developed for this study includes new high-speed, intercity, and regional equipment currently in operation or planned for operation overseas. It also lists several types of rolling stock that are currently in service in the United States and may take value from the results of this project. The focus of the study was limited to technologies that fall within U.S. Tier I operations; as such, the equipment listed have maximum operating speeds not exceeding 125 mph (201 km/h).

Equipment with higher maximum speeds (such as Tier II equipment) was excluded, even though it is possible that an operator might purchase such equipment but only operate it up to 125 mph (201 km/h). Similarly, existing equipment being operated up to 90 mph (145 km/h) already in use in the United States was excluded, even if it might be capable of being qualified for higher speed operation. The matrix could be expanded to include both Tier II and existing equipment.

6.3 Generic Model Development and Simulations

The original intent of the project was to use the developed matrix of truck types to identify specific trucks to perform detailed vehicle-track interaction simulations. The manufacturers were invited to provide data for developing accurate models, but most of them provided only limited data or declined to participate. Therefore, it was agreed with FRA to continue only with the information already on hand and supplement it with data available through TTCI's simulation model databases and experience.

Because no significant truck data design was available, it was not possible to achieve the stated objective of updating the 1996 truck design data report [3].

Five representative truck models were developed for comparative analyses that were intended to represent generic design types typical of those in the matrix of one design. They were not intended to represent any particular designs in the matrix. Data to generate these models was taken from existing published data, the limited data provided by manufacturers, and TTCI's past experience.

To limit project variables, the trucks were modeled under only two different carbodies, a single-level car and a bi-level car. The general dimensions and weights for these two carbodies were taken from the PRIIA requirements for single-level and bi-level car designs.

Results of the simulations are summarized in Section 6.3.1.

6.3.1 AAR Chapter 11

Table 41 and Table 42 summarize the AAR Chapter 11 results for the single-level and bi-level cars. The equalizer beam and radial arm trucks meet criteria in all regimes, whereas the conical spring, journal spring and rubber chevron trucks do not meet criteria in a few regimes. The rubber chevron truck is the only truck to exceed the truck hunting criteria. Because the models used were hypothetical, these results do not indicate that these suspension designs have intrinsically poorer dynamic performance. Instead, these results demonstrate that a truck and/or car designer would need to fine-tune the suspension to meet the needs of good safety performance.

Table 41. Single-Level AAR Chapter 11 Results

AAR Chapter 11 Regime	Maximum Analysis Speed (mph)	Single-Level Truck Type (exceedance speed in mph)				
		Conical Spring	Equalizer Beam	Journal Spring	Radial Arm	Rubber Chevron
Constant Curving	32	Met	Met	Met	Met	Met
Dynamic Curving	32	Met	Met	Met	Met	24(cw*) 32(ccw*)

AAR Chapter 11 Regime	Maximum Analysis Speed (mph)	Single-Level Truck Type (exceedance speed in mph)				
Limiting Spiral	32	Met	Met	10-18 (ccw)	Met	Met
Bunched Spiral	32	Met	Met	Met	Met	12 (cw) 24 (cw)
Pitch & Bounce	105	Met	Met	Met	Met	Met
Twist & Roll	105	Met	Met	Met	Met	Met
Yaw & Sway	105	90–105	Met	Met	Met	Met
High-Speed Stability	135	Met	Met	Met	Met	110

*cw = clockwise; **ccw = counterclockwise

Table 42. Bi-Level AAR Chapter 11 Results

AAR Chapter 11 Regime	Maximum Analysis Speed (mph)	Bi-Level Truck Type (exceedance speed in mph)				
		Conical Spring	Equalizer Beam	Journal Spring	Radial Arm	Rubber Chevron
Constant Curving	32	Met	Met	Met	Met	Met
Dynamic Curving	32	Met	Met	Met	Met	Met
Limiting Spiral	32	Met	Met	Met	Met	Met
Bunched Spiral	32	Met	Met	Met	Met	Met
Pitch & Bounce	105	Met	Met	Met	Met	Met
Twist & Roll	105	Met	Met	Met	Met	Met
Yaw & Sway	105	40	Met	Met	Met	Met
High-Speed Stability	135	Met	Met	Met	Met	110

6.3.2 FRA MCAT

Table 43 and Table 44 summarize the FRA MCAT results for the single-level and bi-level cars. All truck designs exceed criteria in a few regimes, with the conical spring and rubber chevron trucks showing considerable more exceedances than the equalizer beam, journal spring, and radial arm truck designs. Because the models used were hypothetical, these results do not indicate that these suspension designs have intrinsically poorer dynamic performance. Instead, these results demonstrate that a truck and/or car designer would need to fine-tune the suspension to meet the needs of good safety performance.

Table 43. Single-Level MCAT Results, Number of Exceedances

Truck Design	Gage	Min Wheel Vertical Load Ratio	Max. Wheel L/V Ratio	Max. Net Axle L/V Ratio	Max. Truck Side L/V Ratio	Max. Carbody Lateral Peak to Peak Accel	Max. Carbody Vertical Peak to Peak Accel	Carbody Lateral (sustained Oscillatory)	Carbody Vertical (sustained Oscillatory)	Max. Truck Lateral Accel
Conical Spring	56.5	0	3	19	13	14	4	31	0	36
	57.0	0	0	5	5	27	3	26	0	27
Equalizer Beam	56.5	0	0	0	0	12	0	13	0	14
	57.0	0	0	3	0	9	0	9	0	0
Journal Spring	56.5	0	0	0	0	6	0	12	0	0
	57.0	0	0	0	0	8	0	9	0	0
Radial Arm	56.5	0	0	0	0	12	0	12	0	0
	57.0	0	0	1	1	10	0	10	0	1
Rubber Chevron	56.5	0	6	28	29	33	0	35	0	30
	57.0	0	0	3	2	25	0	27	0	1

Table 44. Bi-Level MCAT Results, Number of Exceedances

Truck Design	Gage	Min Wheel Vertical Load Ratio	Max. Wheel L/V Ratio	Max. Net Axle L/V Ratio	Max. Truck Side L/V Ratio	Max. Carbody Lateral Peak to Peak Accel	Max. Carbody Vertical Peak to Peak Accel	Carbody Lateral (sustained Oscillatory)	Carbody Vertical (sustained Oscillatory)	Max. Truck Lateral Accel
Conical Spring	56.5	3	0	12	0	12	11	36	2	36
	57.0	8	0	9	8	9	9	17	2	27
Equalizer Beam	56.5	0	0	6	0	12	0	12	0	3
	57.0	0	0	6	0	9	0	9	0	0
Journal Spring	56.5	0	0	0	0	10	0	17	0	0
	57.0	0	0	0	0	9	0	9	0	0
Radial Arm	56.5	0	0	0	0	12	0	19	0	0
	57.0	0	0	0	0	9	0	15	0	0
Rubber Chevron	56.5	1	2	20	15	29	0	33	0	9
	57.0	0	0	3	3	26	0	27	0	2

6.3.3 Wheel Load Equalization, Static Lean and Low Speed Advisory Results

Table 45 and Table 46 summarize the wheel load equalization, static lean, and low speed advisory results for the single-level and bi-level cars. The equalizer beam truck shows the best performance at equalizing vertical wheel loads, whereas the journal spring truck shows the worst performance. All trucks meet the static lean performance criteria. The equalizer beam truck shows the best performance in the low speed derailment simulations, and the journal spring truck shows the worst performance. The performance ranking of the different trucks in the low speed derailment results are similar to their ranking in wheel load equalization, because good wheel load equalization is required to negotiate the severe perturbations. These results demonstrate that a truck and/or car designer would need to fine-tune the suspension to meet the needs of good safety performance.

Table 45. Single-Level Results: Wheel Load Equalization, Static Lean and Low Speed Advisory

Test Regime		Single-Level Truck Type				
		Conical Spring	**Equalizer Beam**	**Journal Spring**	**Radial Arm**	**Rubber Chevron**
Wheel Load Equalization (% of static load)	2.5 inch	30.1	57.3	12.8	31.9	28.6
	3 inch	16.4	49.2	0	17.0	15.4
Static Lean (% of static load)	6 inch	79.0	81.7	78.0	80.2	61.7
	7 inch	75.7	78.9	74.4	77.0	58.8
Low Speed Derail (perturbation amplitude for exceedance, inches)	10 foot	2.0	2.5	1.5	2.0	2.0
	20 foot	2.0	2.5	1.5	2.0	1.5
	40 foot	2.5	3.0	1.5	2.5	2.0
	62 foot	3.0	3.0	2.0	3.0	2.5

Table 46. Bi-Level Results: Wheel Load Equalization, Static Lean and Low Speed Advisory

Test Regime		Bi-Level Truck Type				
		Conical Spring	**Equalizer Beam**	**Journal Spring**	**Radial Arm**	**Rubber Chevron**
Wheel Load Equalization (% of static load)	2.5 inch	55.5	69.0	42.5	54.3	55.4
	3 inch	46.7	63.4	31.6	44.6	47.2
Static Lean (% of static load)	6 inch	67.6	71.6	67.0	68.8	65.9
	7 inch	61.7	66.8	61.5	63.7	60.4
Low Speed Derail (perturbation amplitude for exceedance, inches)	10 foot	3.0	3.0	2.0	2.5	2.5
	20 foot	3.0	Met	2.0	3.0	3.0
	40 foot	Met	Met	2.5	Met	Met
	62 foot	Met	Met	3.0	Met	Met

6.3.4 Parametric Variations to Identify Design Improvements

At the onset of the project, TTCI intended to provide descriptions of methods for evolving existing technologies into the U.S. operating environment. This was intended to include suggesting retrofit strategies for upgrading existing trucks. However, there was insufficient data available for actual truck designs, so it was not possible to evaluate the technologies and develop specific recommendations. Therefore, a few example parametric evaluations were conducted to demonstrate the types of evaluations a truck designer would need to conduct to optimize its designs.

- To evaluate the hunting performance of the rubber chevron suspension, parameter variations of the primary suspension longitudinal stiffness were made by increasing the longitudinal stiffness by 50 percent and 100 percent on the single-level car. The results showed a slight reduction of both maximum lateral acceleration and standard deviation of the lateral acceleration. However, results still exceeded the performance criteria above 105 mph (169 km/h).
- To evaluate the static wheel unloading and low speed flange climb derailment performance of the journal spring truck, a vertical suspension stiffness parameter variation was used by reducing the vertical primary stiffness by 30 percent. Results showed that reducing the vertical primary stiffness improved the vertical wheel unloading and produced a notable improvement in low speed flange climb derailment performance.

Although these were not exhaustive parameter variations, they do demonstrate how tuning of the suspension could improve performance in specific regimes. To completely optimize a particular truck design, the revised suspension design would need to be reevaluated against all the different performance regimes to verify that the change did not adversely affect performance in any other performance regime.

6.3.5 Single Wheel L/V Static Wheel Load Evaluation Criteria

A significant conclusion of the Low Speed Derailment Advisory simulations is that the 5-foot distance to climb criterion specified in 49 CFR § 213.345 is probably too long for the evaluation of low speed derailment. A shorter criterion such as the 50 msec criterion specified in AAR Chapter 11 appears to be more appropriate for the evaluation of low speed flange climb performance.

In addition, the 10 percent of static wheel load vertical wheel load criterion may not be conservative enough for evaluation of low speed derailment performance and wheel load equalization. A criterion of 30 percent such as used in some Asian and European specifications may be more appropriate.

6.4 Quantifying the Load Environment

Simulations were conducted to compare the performance of the five different passenger trucks to three typical freight cars in terms of rail wear indices and vertical and lateral forces imparted to the track. Simulations were conducted using measured track geometry from three different shared corridors:

- Atlanta, GA – Charlotte, NC
- Alton, IL – Joliet, IL
- North Portland, OR – Eavan, WA

Simulation results showed that:

- The equalizer beam design generates more rail wear comparative to the other designs
- The radial arm and journal spring designs generate the next highest rail wear

- The conical spring design generates the lowest predicted rail wear trend
- The freight cars generate lower high rail wear indices than the passenger cars, but generate much higher low rail wear indices
- The three freight cars all generate similar rail wear indices
- The rubber chevron design generates the smallest dynamic vertical load distribution, followed by the auto-rack freight car, the journal spring, the conical spring, the radial arm and equalizer beam truck designs, and the loaded hopper and double stack freight cars generate much higher dynamic vertical loads
- The rubber chevron and conical spring truck designs produce the lowest lateral dynamic forces, and the loaded hopper and double stack freight cars generate larger dynamic lateral forces than all the passenger truck designs

In actual practice, it is likely that many more freight cars will operate over a given shared corridor than passenger cars. Therefore, results should be convolved with expected passenger and freight tonnage for any particular route to establish the cumulative predicted load environment and wear effects from each type of service.

6.4.1 Ride Quality

Simulations to evaluate ride quality were performed using a one-mile track segment from measured track geometry from the Alton-to-Joliet route. The results show that the hypothetical conical spring and rubber chevron designs had poorer ride quality than the other three designs. Because the models used were hypothetical, these results do not indicate that these suspension designs have intrinsically worse ride quality. Instead, these results demonstrate that a truck and/or car designer would need to fine-tune the suspension to meet both the needs of good ride quality and safety performance.

6.5 Example Simulation Validation and Test Matrices

Each vehicle and suspension design will have unique simulation and test requirements specific to their design details and intended service. Tests are required to validate computer simulations and to meet vehicle qualification requirements. Example simulation and test matrices were developed for analysis of vehicle performance for a typical car with air suspension. These were developed from the following sources and TTCI experience with the analysis and testing of numerous different passenger vehicle designs:

- 49 CFR Part 213 Subpart G, Train Operation at Track Classes 6 and Higher [1]:
    - § 213.345, Vehicle/track system qualification
    - Appendix D, Minimally Compliant Analytical Track (MCAT) Simulations Used for Qualifying Vehicles To Operate at High Speeds and at High Cant Deficiencies
- 49 CFR § 213.329 – Curves; elevation and speed limitations
- 78 FR 16358 FRA Safety Advisory 2013-02; Low-Speed, Wheel Climb Derailments of Passenger Equipment with “Stiff” Suspension Systems [66]

- APTA PR-M-S-014-006, standard for Wheel Load Equalization of Passenger Railroad Rolling Stock [68]
- Vehicle design specifications (such as PRIIA)

Because most high-speed passenger vehicles will also be required to operate safely at lower speeds on Track Class 5 and lower, analyses and tests were also recommended to address evaluation of performance at lower speeds on lower classes of track as well.

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Appendix A.
Candidate Truck Matrix

Table A. Candidate Track Matrix (v.12.13)

Candidate Truck Matrix (v.12.13)

Car/Trainset	Primary Car/Trainset Manufacturer	Owner/Operator	Series Name	Operation	Body Type	Body Width	Car/Trainset Max Operating Speed mph (km/h)	Truck Maximum Speed mph (km/h)	Car/Trainset Weight (Tare) tons (tonnes)	Truck	Truck Manufacturer	Powered/ Unpowered	Gauge in (mm)	Primary Suspension	Secondary Suspension	Bearing Location	Specialized Feature 1	Specialized Feature 2	Specialized Feature 3	Type of Braking System	Additional Comments
Coradia Duplex	Alstom	SNCF (France)	SNCF Class Z 26500	Intercity	Multi-Level EMU	Standard Body	99 (160)	99 (160)	N/A	"COR-1"	Alstom	Both	56.5 (1435)	Journal Spring	Air Spring	Outboard	N/A	N/A	N/A	Dynamic - regen Friction - disc (axle)	Other versions of Coradia are available (e.g. low floor Coradia Continental, DMU Coradia Lint, etc.).
IC4	Ansaldo Breda	DSB (Denmark)	DSB Class MG	Intercity	Single Level DMU	Standard Body	124 (200)	124 (200)	[4] 154.3 (140)	"IC4-1"	Ansaldo Breda	Both	56.5 (1435)	Journal Spring	Air Spring Center Pivot	Outboard	Articulated Cars	N/A	N/A	Dynamic Friction - disc (axle) Track brakes	
Single Level EMU	Bombardier	LIRR (US)	M-7	Regional	Single Level EMU	Standard Body	99 (160)	99 (160)	[1] 64.6 (58.6)	"BOM-1"	Bombardier	Powered	56.5 (1435)	Journal Spring	Air Spring Bolsterless	Outboard	N/A	N/A	N/A	Dynamic Friction - disc/tread	
Single Level Coaches	Bombardier	NJT (US)	Comet III	Regional	Single Level Trailer	Standard Body	120 (193)	120 (193)	[1] 45 (40.8)	G70-I	GSI	Unpowered	56.5 (1435)	Equalizer	Air Spring Bolster Center Pivot	Inboard	N/A	N/A	N/A	Friction - tread	
Bilevel Coaches	Bombardier	Amtrak (US)	Superliner II	Intercity	Multi-Level Trailer	Standard Body	110 (177)	125 (201)	[1] 77.5 (70.3)	G70-O	GSI	Unpowered	56.5 (1435)	Equalizer	Coil Spring Bolster Center Pivot	Outboard	N/A	N/A	N/A	Friction - disc (axle)/tread	
Single Level Coaches	Bombardier	Amtrak (US)	Horizon	Intercity	Single Level Trailer	Standard Body	125 (201)	125 (201)	[1] 58 (52.6)	G70-O	GSI	Unpowered	56.5 (1435)	Equalizer	Coil Spring Bolster Center Pivot	Outboard	N/A	N/A	N/A	Friction	
AGC	Bombardier	SNCF (France)	SNCF Class B 82500	Regional	Single Level Dual	Standard Body	99 (160)	99 (160)	N/A	FLEXX Compact	Bombardier	Both	56.5 (1435)	Journal Spring	Air Spring	Outboard	Articulated Cars	N/A	N/A	Dynamic Friction - disc (cheek)	
Talent	Bombardier	NSB (Norway)	NSB Class 93	Regional	Single Level DMU	Standard Body	87 (140)	99 (160)	[2] 84.9 (77)	FLEXX Compact	Bombardier	Both	56.5 (1435)	Journal Spring	Air Spring	Outboard	Articulated Cars	Passive Tilt	N/A	Dynamic Friction - disc (cheek)	
Talent 2	Bombardier	DB (Germany)	Class 442 (DB)	Regional	Single Level EMU	Standard Body	99 (160)	99 (160)	N/A	FLEXX Compact	Bombardier	Both	56.5 (1435)	Journal Spring	Air Spring	Outboard	Articulated Cars	N/A	N/A	Dynamic Friction - disc (cheek)	
Twindexx Express	Bombardier	SBB (Switzerland)	SBB RABDe 502	Intercity	Multi-Level Trailer	Standard Body	124 (200)	143 (230)	[1] 55.1 (50)	FLEXX Tronic WAKO	Bombardier	Unpowered	56.5 (1435)	Journal Spring	Airspring Bolster	Outboard	Active Radial Steering	Active Tilt	N/A	Friction	This car is part of a 656 ft (200 m), 8-car trainset.
Twindexx Express	Bombardier	SBB (Switzerland)	SBB RABDe 502	Intercity	Multi-Level Power	Standard Body	124 (200)	143 (230)	[1] 57.3 (52)	FLEXX Tronic WAKO	Bombardier	Powered	56.5 (1435)	Journal Spring	Airspring Bolster	Outboard	Active Radial Steering	Active Tilt	N/A	Dynamic Friction	This car is part of a 656 ft (200 m), 8-car trainset.
Regina	Bombardier	SJ (Sweden)	SJ 3000	Intercity	Single Level EMU	Wide Body	124 (200)	155 (250)	[2] 132.3 (120)	FLEXX Link	Bombardier	Both	56.5 (1435)	Radial Arm Coil Spring/Rubber	Air Spring	Outboard	N/A	N/A	N/A	Dynamic Friction - disc (cheek) Track brakes	
Meridian (Voyager)	Bombardier	EMT (UK)	BR Class 222	Intercity	Single Level DMU	Standard Body	124 (200)	124 (200)	N/A	FLEXX Eco	Bombardier	Both	56.5 (1435)	Rubber Metacone Spring Flexible Frame	Air Spring Bolster Center Pivot	Inboard	N/A	N/A	N/A	Dynamic - rheo Friction - disc (cheek) Track brakes (optional)	
Civity	CAF	Concept	N/A	Regional	Single Level EMU	Standard Body	124 (200)	124 (200)	[3] 110.2 (100)	"CIV-1"	CAF	Both	56.5 (1435)	Journal Spring	Air Spring	Outboard	Articulated Cars	N/A	N/A	Dynamic Friction - disc (cheek)	This trainset is available with electric, mechanical diesel/hydraulic diesel, electric- diesel, or dual tractions. It can be configured as 3, 4, 5, 6, 7, or 8 cars.
Hanvit 200	Hyundai Rotem	Korail (Korea)	TX	High Speed	Single Level EMU	Standard Body	112 (180)	124 (200)	[6] 379.2 (344)	"HAN-1"	Hyundai Rotem	Both	56.5 (1435)	Journal Spring	Air Spring Bolster	Outboard	Active Radial Steering	Active Tilt	N/A	Dynamic - regen Friction - disc (cheek)	
Bilevel Coaches	Hyundai Rotem	SCRRA (US)	Bilevel Coaches	Regional	Multi-Level Trailer	Wide Body	112 (180)	112 (180)	N/A	"HRU-1"	Hyundai Rotem	Unpowered	56.5 (1435)	Rubber Chevron	Air Spring Bolster	Inboard	N/A	N/A	N/A	Friction - disc (axle)	
EMU	Hyundai Rotem	SEPTA (US)	Silverliner V	Regional	Single Level EMU	Wide Body	99 (160)	110 (177)	N/A	"HRU-2"	Hyundai Rotem	Both	56.5 (1435)	Rubber Chevron	Air Spring Bolster	Inboard	N/A	N/A	N/A	Friction - disc (axle)	
Bilevel Coaches	Kawasaki	MBTA (US)	BTC-4	Regional	Multi-Level Trailer	Standard Body	87 (140)	87 (140)	[1] 62.9 (57.1)	"KAW-2"	Kawasaki	Unpowered	56.5 (1435)	Radial Arm	Air Spring Bolster Center Pivot	Outboard	N/A	N/A	N/A	Friction - disc/tread	
Single Level EMU	Kawasaki	MNCR (US)	M-8	Regional	Single Level EMU	Standard Body	99 (160)	99 (160)	N/A	"KAW-3"	Kawasaki	Powered	56.5 (1435)	Radial Arm	Air Spring Bolsterless	Outboard	N/A	N/A	N/A	Dynamic Friction	
Bilevel Coaches	Kawasaki	LIRR (US)	C-3	Regional	Multi-Level Trailer	Standard Body	99 (160)	99 (160)	[1] 71.1 (64.5)	"KAW-1"	Kawasaki	Unpowered	56.5 (1435)	Radial Arm	Air Spring	Outboard	N/A	N/A	N/A	Friction - disc/tread	
Bilevel Coaches	Nippon Sharyo	VRE (US)	N/A	Regional	Multi-Level Trailer	Standard Body	79 (127)	79 (127)	[1] 63.0 (57.2)	"VRE-1"	Nippon Sharyo	Unpowered	56.5 (1435)	Equalizer	Swing Hanger	Outboard	N/A	N/A	N/A	Friction	This coach was developed jointly with Sumitomo.
Single Level Coaches	Nippon Sharyo	MARC (US)	MARC II	Regional	Single Level Trailer	Standard Body	110 (177)	124 (200)	[1] 55.5 (50.4)	NT 319	Nippon Sharyo	Unpowered	56.5 (1435)	Journal Spring	Air Spring Bolster Center Pivot	Outboard	N/A	N/A	N/A	Friction - disc (axle)/tread	
Desiro ML	Siemens	Transregio (Germany) SNCB (Belgium) OBB (Austria)	Class 460 (Transregio)	Regional	Single Level EMU	Standard Body	99 (160)	99 (160)	[3] 145.5 (132)	SF 6500 TDG SF 6500 LDG	Siemens	Both	56.5 (1435)	Journal Spring	Air Spring Center Pivot	Outboard	Passive Steering	N/A	N/A	Dynamic Friction - disc (cheek) Track brakes (optional)	The Desiro ML trainset is also available as a DMU.
ICE TD (Venturio)	Siemens	DB (Germany) DSB (Denmark)	Class 605 (DB)	High Speed	Single Level DMU	Standard Body	124 (200)	155 (250)	[4] 255.7 (232)	SF 600 TDG SF 600 LDG	Siemens	Both	56.5 (1435)	Journal Spring	Air Spring Bolster Pivot	Outboard	Passive Steering	Active Tilt	N/A	Dynamic - rheo Friction - disc (cheek) Track brakes (optional)	
Desiro Double Deck	Siemens	SBB (Switzerland)	SBB RABe 514	Regional	Multi-Level EMU	Standard Body	87 (140)	174 (280)	[4] 240.3 (218)	SF 400	Siemens	Unpowered	56.5 (1435)	Journal Spring Flexible Frame	Air Spring Center Pivot	Outboard	Passive Steering	N/A	N/A	Friction - disc (axle)	The information shown is for the SF 400 truck. It is expected that there is a version of this truck that accommodates double-deck coaches (i.e. SF 400 DSW).
Viaggio Light	Siemens	ISR (Israel)	SDPP	Regional	Single Level Trailer	Standard Body	99 (160)	124 (200)	[1] 47.4 (43)	SF 300	Siemens	Unpowered	56.5 (1435)	Journal Spring Flexible Frame	Coil Spring Bolster Center Pivot	Outboard	Passive Steering	N/A	N/A	Friction - disc (axle) Electromagnetic track brake	
Desiro Classic	Siemens	NCTD (US)	Sprinter	Regional	Single Level DMU	Standard Body	75 (120)	75 (120)	[2] 77.2 (70)	SF 4000 TDG SF 4000 JLDG	Siemens	Both	56.5 (1435)	Metal-Rubber Conical Sleeve Springs	Air Spring Bolster Center Pivot	Outboard	N/A	N/A	N/A	Friction - disc (m - axle) Friction - disc (t - cheek) Track brakes (m - optional)	
Desiro Double Deck	Siemens	SBB (Switzerland)	SBB RABe 514	Regional	Multi-Level EMU	Standard Body	87 (140)	87 (140)	[4] 240.3 (218)	SF 500 DSW	Siemens	Powered	56.5 (1435)	Radial Arm	Air Spring Bolster Center Pivot	Outboard	Passive Steering	N/A	N/A	Dynamic Friction - disc (cheek)	
Desiro EMU	Siemens	OSE (Greece)	OSE Class 460	Regional	Single Level EMU	Standard Body	99 (160)	124 (200)	[5] 165.4 (150)	SF 5000 E TDG SF 5000 LDG SF 5000 JTDG SF 5000 JLDG	Siemens	Both	56.5 (1435)	Radial Arm	Air Spring Bolster/Bolsterless	Outboard	Passive Steering	N/A	N/A	Dynamic Friction - disc (cheek)	
FLIRT EMU	Stadler	SBB (Switzerland)	SBB RABe 523	Regional	Single Level EMU	Standard Body	99 (160)	99 (160)	[4] 132.3 (120)	"FLI-1" "FLI-2"	Stadler/LRS	Both	56.5 (1435)	Journal Spring	Air Spring	Outboard	Articulated Cars	N/A	N/A	Dynamic - regen/rheo Friction - disc (cheek)	Stadler's FLIRTs are also available as DMUs. The most recent trainsets (e.g. EMUs/DMUs for Elektriraudtee (Estonia) and the FLIRT EMU 3 for Veolia (Germany) have trucks of different wheelbases and wheel diameters.
GTW DMU-2 2/6	Stadler	DCTA (US)	A-Train	Regional	Single Level DMU	Standard Body	75 (120)	99 (160)	[3] 80.0 (72.2)	"GTW-1" "GTW-2"	Stadler/LRS	Both	56.5 (1435)	Journal Spring	Air Spring	Outboard	Articulated Cars	N/A	N/A	Dynamic Friction - disc (cheek/axle)	
GTW	Stadler	Veolia Transport (Netherlands)	GTW EMU 2/6	Regional	Single Level EMU	Standard Body	87 (140)	99 (160)	[3] 72.2 (65.5)	"GTW-1" "GTW-2"	Stadler/LRS	Both	56.5 (1435)	Journal Spring	Air Spring	Outboard	Articulated Cars	N/A	N/A	Dynamic Friction - disc (cheek/axle)	
KISS	Stadler	SBB (Switzerland)	SBB RABe 511	Regional	Multi-Level EMU	Standard Body	99 (160)	124 (200)	[6] 327.4 (297)	"KIS-1"	Stadler	Both	56.5 (1435)	Journal Spring	Air Spring	Outboard	N/A	N/A	N/A	Dynamic Friction - disc (cheek)	Maximum truck speed shown is based on the KISS trainset for Westbahn (Austria), which has a maximum trainset operating speed of 124 mph (200 km/h).

Appendix B.
Truck Categories

Table B1. Journal Spring – Air Spring – Outboard Bearings (v.12.13)

Journal Spring – Air Spring – Outboard Bearings (v.12.13)

Car/Trainset	Primary Car/Trainset Manufacturer	Owner/Operator	Series Name	Operation	Body Type	Body Width	Car/Trainset Max Operating Speed mph (km/h)	Truck Maximum Speed mph (km/h)	Car/Trainset Weight (Tare) tons (tonnes)	Truck	Truck Manufacturer	Powered/ Unpowered	Gauge in (mm)	Primary Suspension	Secondary Suspension	Bearing Location	Specialized Feature 1	Specialized Feature 2	Specialized Feature 3	Type of Braking System	Additional Comments
Coradia Duplex	Alstom	SNCF (France)	SNCF Class Z 26500	Intercity	Multi-Level EMU	Standard Body	99 (160)	99 (160)	N/A	"COR-1"	Alstom	Both	56.5 (1435)	Journal Spring	Air Spring	Outboard	N/A	N/A	N/A	Dynamic - regen Friction - disc (axle)	Other versions of Coradia are available (e.g., low floor Coradia Continental, DMU Coradia Lint, etc.).
AGC	Bombardier	SNCF (France)	SNCF Class B 82500	Regional	Single Level Dual	Standard Body	99 (160)	99 (160)	N/A	FLEXX Compact	Bombardier	Both	56.5 (1435)	Journal Spring	Air Spring	Outboard	Articulated Cars	N/A	N/A	Dynamic Friction - disc (cheek)	
Talent	Bombardier	NSB (Norway)	NSB Class 93	Regional	Single Level DMU	Standard Body	87 (140)	99 (160)	[2] 84.9 (77)	FLEXX Compact	Bombardier	Both	56.5 (1435)	Journal Spring	Air Spring	Outboard	Articulated Cars	Passive Tilt	N/A	Dynamic Friction - disc (cheek)	
Talent 2	Bombardier	DB (Germany)	Class 442 (DB)	Regional	Single Level EMU	Standard Body	99 (160)	99 (160)	N/A	FLEXX Compact	Bombardier	Both	56.5 (1435)	Journal Spring	Air Spring	Outboard	Articulated Cars	N/A	N/A	Dynamic Friction - disc (cheek)	
Civity	CAF	Concept	N/A	Regional	Single Level EMU	Standard Body	124 (200)	124 (200)	[3] 110.2 (100)	"CIV-1"	CAF	Both	56.5 (1435)	Journal Spring	Air Spring	Outboard	Articulated Cars	N/A	N/A	Dynamic Friction - disc (cheek)	This trainset is available with electric, mechanical diesel/hydraulic diesel, electric- diesel, or dual tractions. It can be configured as 3, 4, 5, 6, 7, or 8 cars.
FLIRT EMU	Stadler	SBB (Switzerland)	SBB RABe 523	Regional	Single Level EMU	Standard Body	99 (160)	99 (160)	[4] 132.3 (120)	"FLI-1" "FLI-2"	Stadler/LRS	Both	56.5 (1435)	Journal Spring	Air Spring	Outboard	Articulated Cars	N/A	N/A	Dynamic - regen/rheo Friction - disc (cheek)	Stadler's FLIRTs are also available as DMUs. The most recent trainsets (e.g. EMUs/DMUs for Elektriraudtee (Estonia) and the FLIRT EMU 3 for Veolia (Germany) have trucks of different wheelbases and wheel diameters.
GTW DMU-2 2/6	Stadler	DCTA (US)	A-Train	Regional	Single Level DMU	Standard Body	75 (120)	99 (160)	[3] 80.0 (72.2)	"GTW-1" "GTW-2"	Stadler/LRS	Both	56.5 (1435)	Journal Spring	Air Spring	Outboard	Articulated Cars	N/A	N/A	Dynamic Friction - disc (cheek/axle)	
GTW	Stadler	Veolia Transport (Netherlands)	GTW EMU 2/6	Regional	Single Level EMU	Standard Body	87 (140)	99 (160)	[3] 72.2 (65.5)	"GTW-1" "GTW-2"	Stadler/LRS	Both	56.5 (1435)	Journal Spring	Air Spring	Outboard	Articulated Cars	N/A	N/A	Dynamic Friction - disc (cheek/axle)	
KISS	Stadler	SBB (Switzerland)	SBB RABe 511	Regional	Multi-Level EMU	Standard Body	99 (160)	124 (200)	[6] 327.4 (297)	"KIS-1"	Stadler	Both	56.5 (1435)	Journal Spring	Air Spring	Outboard	N/A	N/A	N/A	Dynamic Friction - disc (cheek)	Maximum truck speed shown is based on the KISS trainset for Westbahn (Austria), which has a maximum trainset operating speed of 124 mph (200 km/h).

Table B2. Journal Spring – Air Spring Center Pivot – Outboard Bearings (v.12.13)

Journal Spring – Air Spring Center Pivot – Outboard Bearings (v.12.13)

Car/Trainset	Primary Car/Trainset Manufacturer	Owner/Operator	Series Name	Operation	Body Type	Body Width	Car/Trainset Max Operating Speed mph (km/h)	Truck Maximum Speed mph (km/h)	Car/Trainset Weight (Tare) tons (tonnes)	Truck	Truck Manufacturer	Powered/ Unpowered	Gauge in (mm)	Primary Suspension	Secondary Suspension	Bearing Location	Specialized Feature 1	Specialized Feature 2	Specialized Feature 3	Type of Braking System	Additional Comments
IC4	Ansaldo Breda	DSB (Denmark)	DSB Class MG	Intercity	Single Level DMU	Standard Body	124 (200)	124 (200)	[4] 154.3 (140)	"IC4-1"	Ansaldo Breda	Both	56.5 (1435)	Journal Spring	Air Spring Center Pivot	Outboard	Articulated Cars	N/A	N/A	Dynamic Friction - disc (axle) Track brakes	
Desiro ML	Siemens	Transregio (Germany) SNCB (Belgium) OBB (Austria)	Class 460 (Transregio)	Regional	Single Level EMU	Standard Body	99 (160)	99 (160)	[3] 145.5 (132)	SF 6500 TDG SF 6500 LDG	Siemens	Both	56.5 (1435)	Journal Spring	Air Spring Center Pivot	Outboard	Passive Steering	N/A	N/A	Dynamic Friction - disc (cheek) Track brakes (optional)	The Desiro ML trainset is also available as a DMU.

Table B3. Journal Spring – Air Spring/Bolster – Outboard Bearings (v.12.13)

Journal Spring – Air Spring/Bolster – Outboard Bearings (v.12.13)

Car/Trainset	Primary Car/Trainset Manufacturer	Owner/Operator	Series Name	Operation	Body Type	Body Width	Car/Trainset Max Operating Speed mph (km/h)	Truck Maximum Speed mph (km/h)	Car/Trainset Weight (Tare) tons (tonnes)	Truck	Truck Manufacturer	Powered/ Unpowered	Gauge in (mm)	Primary Suspension	Secondary Suspension	Bearing Location	Specialized Feature 1	Specialized Feature 2	Specialized Feature 3	Type of Braking System	Additional Comments
Twindexx Express	Bombardier	SBB (Switzerland)	SBB RABDe 502	Intercity	Multi-Level Trailer	Standard Body	124 (200)	143 (230)	[1] 55.1 (50)	FLEXX Tronic WAKO	Bombardier	Unpowered	56.5 (1435)	Journal Spring	Airspring Bolster	Outboard	Active Radial Steering	Active Tilt	N/A	Friction	This car is part of a 656 ft (200 m), 8-car trainset.
Twindexx Express	Bombardier	SBB (Switzerland)	SBB RABDe 502	Intercity	Multi-Level Power	Standard Body	124 (200)	143 (230)	[1] 57.3 (52)	FLEXX Tronic WAKO	Bombardier	Powered	56.5 (1435)	Journal Spring	Airspring Bolster	Outboard	Active Radial Steering	Active Tilt	N/A	Dynamic Friction	This car is part of a 656 ft (200 m), 8-car trainset.
Hanvit 200	Hyundai Rotem	Korail (Korea)	TTX	High Speed	Single Level EMU	Standard Body	112 (180)	124 (200)	[6] 379.2 (344)	"HAN-1"	Hyundai Rotem	Both	56.5 (1435)	Journal Spring	Air Spring Bolster	Outboard	Active Radial Steering	Active Tilt	N/A	Dynamic - regen Friction - disc (cheek)	
Single Level Coaches	Nippon Sharyo	MARC (US)	MARC II	Regional	Single Level Trailer	Standard Body	110 (177)	124 (200)	[1] 55.5 (50.4)	NT 319	Nippon Sharyo	Unpowered	56.5 (1435)	Journal Spring	Air Spring Bolster Center Pivot	Outboard	N/A	N/A	N/A	Friction - disc (axle)/tread	
ICE TD (Venturio)	Siemens	DB (Germany) DSB (Denmark)	Class 605 (DB)	High Speed	Single Level DMU	Standard Body	124 (200)	155 (250)	[4] 255.7 (232)	SF 600 TDG SF 600 LDG	Siemens	Both	56.5 (1435)	Journal Spring	Air Spring Bolster Pivot	Outboard	Passive Steering	Active Tilt	N/A	Dynamic - rheo Friction - disc (cheek) Track brakes (optional)	

Table B4. Journal Spring – Air Spring/Bolsterless – Outboard Bearings (v.12.13)

Journal Spring – Air Spring/Bolsterless - Outboard Bearings (v.12.13)

Car/Trainset	Primary Car/Trainset Manufacturer	Owner/Operator	Series Name	Operation	Body Type	Body Width	Car/Trainset Max Operating Speed mph (km/h)	Truck Maximum Speed mph (km/h)	Car/Trainset Weight (Tare) tons (tonnes)	Truck	Truck Manufacturer	Powered/ Unpowered	Gauge in (mm)	Primary Suspension	Secondary Suspension	Bearing Location	Specialized Feature 1	Specialized Feature 2	Specialized Feature 3	Type of Braking System	Additional Comments
Single Level EMU	Bombardier	LIRR (US)	M-7	Regional	Single Level EMU	Standard Body	99 (160)	99 (160)	[1] 64.6 (58.6)	"BOM-1"	Bombardier	Powered	56.5 (1435)	Journal Spring	Air Spring Bolsterless	Outboard	N/A	N/A	N/A	Dynamic Friction - disc/tread	

Table B5. Journal Spring/Flexible Frame – Air spring/Center Pivot – Outboard Bearings (v.12.13)

Journal Spring/Flexible Frame – Air Spring/Center Pivot – Outboard Bearings (v.12.13)

Car/Trainset	Primary Car/Trainset Manufacturer	Owner/Operator	Series Name	Operation	Body Type	Body Width	Car/Trainset Max Operating Speed mph (km/h)	Truck Maximum Speed mph (km/h)	Car/Trainset Weight (Tare) tons (tonnes)	Truck	Truck Manufacturer	Powered/ Unpowered	Gauge in (mm)	Primary Suspension	Secondary Suspension	Bearing Location	Specialized Feature 1	Specialized Feature 2	Specialized Feature 3	Type of Braking System	Additional Comments
Desiro Double Deck	Siemens	SBB (Switzerland)	SBB RABe 514	Regional	Multi-Level EMU	Standard Body	87 (140)	174 (280)	[4] 240.3 (218)	SF 400	Siemens	Unpowered	56.5 (1435)	Journal Spring Flexible Frame	Air Spring Center Pivot	Outboard	Passive Steering	N/A	N/A	Friction - disc (axle)	The information shown is for the SF 400 truck. It is expected that there is a version of this truck that accommodates double-deck coaches (i.e. SF 400 DSW).

Table B6. Journal Spring Flexible Frame – Coil Spring/Bolster/Center Pivot Outboard Bearings (v.12.13)

Journal Spring/Flexible Frame – Coil Spring/Bolster/Center Pivot – Outboard Bearings (v.12.13)

Car/Trainset	Primary Car/Trainset Manufacturer	Owner/Operator	Series Name	Operation	Body Type	Body Width	Car/Trainset Max Operating Speed mph (km/h)	Truck Maximum Speed mph (km/h)	Car/Trainset Weight (Tare) tons (tonnes)	Truck	Truck Manufacturer	Powered/Unpowered	Gauge in (mm)	Primary Suspension	Secondary Suspension	Bearing Location	Specialized Feature 1	Specialized Feature 2	Specialized Feature 3	Type of Braking System	Additional Comments
Viaggio Light	Siemens	ISR (Israel)	SDPP	Regional	Single Level Trailer	Standard Body	99 (160)	124 (200)	[1] 47.4 (43)	SF 300	Siemens	Unpowered	56.5 (1435)	Journal Spring Flexible Frame	Coil Spring Bolster Center Pivot	Outboard	Passive Steering	N/A	N/A	Friction - disc (axle) Electromagnetic track brake	

Table B7. Sleeve Spring – Air Spring/Bolster Center Pivot – Outboard Bearings (v.12.13)

Sleeve Spring – Air Spring/Bolster/Center Pivot – Outboard Bearings (v.12.13)

Car/Trainset	Primary Car/Trainset Manufacturer	Owner/Operator	Series Name	Operation	Body Type	Body Width	Car/Trainset Max Operating Speed mph (km/h)	Truck Maximum Speed mph (km/h)	Car/Trainset Weight (Tare) tons (tonnes)	Truck	Truck Manufacturer	Powered/Unpowered	Gauge in (mm)	Primary Suspension	Secondary Suspension	Bearing Location	Specialized Feature 1	Specialized Feature 2	Specialized Feature 3	Type of Braking System	Additional Comments
Desiro Classic	Siemens	NCTD (US)	Sprinter	Regional	Single Level DMU	Standard Body	75 (120)	75 (120)	[2] 77.2 (70)	SF 4000 TDG SF 4000 JLDG	Siemens	Both	56.5 (1435)	Metal-Rubber Conical Sleeve Springs	Air Spring Bolster Center Pivot	Outboard	N/A	N/A	N/A	Friction - disc (m - axle) Friction - disc (t - cheek) Track brakes (m - optional)	

Table B8. Radial Arm – Air Spring/Bolster/Center Pivot – Outboard Bearings (v.12.13)

Radial Arm – Air Spring/Bolster/Center Pivot – Outboard Bearings (v.12.13)

Car/Trainset	Primary Car/Trainset Manufacturer	Owner/Operator	Series Name	Operation	Body Type	Body Width	Car/Trainset Max Operating Speed mph (km/h)	Truck Maximum Speed mph (km/h)	Car/Trainset Weight (Tare) tons (tonnes)	Truck	Truck Manufacturer	Powered/Unpowered	Gauge in (mm)	Primary Suspension	Secondary Suspension	Bearing Location	Specialized Feature 1	Specialized Feature 2	Specialized Feature 3	Type of Braking System	Additional Comments
Bilevel Coaches	Kawasaki	MBTA (US)	BTC-4	Regional	Multi-Level Trailer	Standard Body	87 (140)	87 (140)	[1] 62.9 (57.1)	"KAW-2"	Kawasaki	Unpowered	56.5 (1435)	Radial Arm	Air Spring Bolster Center Pivot	Outboard	N/A	N/A	N/A	Friction - disc/tread	
Desiro Double Deck	Siemens	SBB (Switzerland)	SBB RABe 514	Regional	Multi-Level EMU	Standard Body	87 (140)	87 (140)	[4] 240.3 (218)	SF 500 DSW	Siemens	Powered	56.5 (1435)	Radial Arm	Air Spring Bolster Center Pivot	Outboard	Passive Steering	N/A	N/A	Dynamic Friction - disc (cheek)	

Table B9. Radial Arm – Arm Spring/Bolsterless – Outboard Bearings (v.12.13)

Radial Arm – Arm Spring/Bolsterless – Outboard Bearings (v.12.13)

Car/Trainset	Primary Car/Trainset Manufacturer	Owner/Operator	Series Name	Operation	Body Type	Body Width	Car/Trainset Max Operating Speed mph (km/h)	Truck Maximum Speed mph (km/h)	Car/Trainset Weight (Tare) tons (tonnes)	Truck	Truck Manufacturer	Powered/Unpowered	Gauge in (mm)	Primary Suspension	Secondary Suspension	Bearing Location	Specialized Feature 1	Specialized Feature 2	Specialized Feature 3	Type of Braking System	Additional Comments
Desiro EMU	Siemens	OSE (Greece)	OSE Class 460	Regional	Single Level EMU	Standard Body	99 (160)	124 (200)	[5] 165.4 (150)	SF 5000 E TDG SF 5000 LDG SF 5000 JTDG SF 5000 JLDG	Siemens	Both	56.5 (1435)	Radial Arm	Air Spring Bolster/Bolsterless	Outboard	Passive Steering	N/A	N/A	Dynamic Friction - disc (cheek)	
Single Level EMU	Kawasaki	MNCR (US)	M-8	Regional	Single Level EMU	Standard Body	99 (160)	99 (160)	N/A	"KAW-3"	Kawasaki	Powered	56.5 (1435)	Radial Arm	Air Spring Bolsterless	Outboard	N/A	N/A	N/A	Dynamic Friction	

Table B10. Radial Arm – Air Spring – Outboard Bearings (v.12.13)

Radial Arm – Air Spring – Outboard Bearings (v.12.13)

Car/Trainset	Primary Car/Trainset Manufacturer	Owner/Operator	Series Name	Operation	Body Type	Body Width	Car/Trainset Max Operating Speed mph (km/h)	Truck Maximum Speed mph (km/h)	Car/Trainset Weight (Tare) tons (tonnes)	Truck	Truck Manufacturer	Powered/Unpowered	Gauge in (mm)	Primary Suspension	Secondary Suspension	Bearing Location	Specialized Feature 1	Specialized Feature 2	Specialized Feature 3	Type of Braking System	Additional Comments
Bilevel Coaches	Kawasaki	LIRR (US)	C-3	Regional	Multi-Level Trailer	Standard Body	99 (160)	99 (160)	[1] 71.1 (64.5)	"KAW-1"	Kawasaki	Unpowered	56.5 (1435)	Radial Arm	Air Spring	Outboard	N/A	N/A	N/A	Friction - disc/tread	

Table B11. Radial Arm/Coil Spring/Rubber – Air Spring – Outboard Bearings (v.12.13)

Radial Arm/Coil Spring/Rubber - Air Spring – Outboard Bearings (v.12.13)

Car/Trainset	Primary Car/Trainset Manufacturer	Owner/Operator	Series Name	Operation	Body Type	Body Width	Car/Trainset Max Operating Speed mph (km/h)	Truck Maximum Speed mph (km/h)	Car/Trainset Weight (Tare) tons (tonnes)	Truck	Truck Manufacturer	Powered/Unpowered	Gauge in (mm)	Primary Suspension	Secondary Suspension	Bearing Location	Specialized Feature 1	Specialized Feature 2	Specialized Feature 3	Type of Braking System	Additional Comments
Regina	Bombardier	SJ (Sweden)	SJ 3000	Intercity	Single Level EMU	Wide Body	124 (200)	155 (250)	[2] 132.3 (120)	FLEXX Link	Bombardier	Both	56.5 (1435)	Radial Arm Coil Spring/Rubber	Air Spring	Outboard	N/A	N/A	N/A	Dynamic Friction - disc (cheek) Track brakes	

Table B12. Rubber Chevron – Air Spring/Bolster – Inboard Bearing (v.12.13)

Rubber Chevron – Air Spring/Bolster – Inboard Bearing (v.12.13)

Car/Trainset	Primary Car/Trainset Manufacturer	Owner/Operator	Series Name	Operation	Body Type	Body Width	Car/Trainset Max Operating Speed mph (km/h)	Truck Maximum Speed mph (km/h)	Car/Trainset Weight (Tare) tons (tonnes)	Truck	Truck Manufacturer	Powered/Unpowered	Gauge in (mm)	Primary Suspension	Secondary Suspension	Bearing Location	Specialized Feature 1	Specialized Feature 2	Specialized Feature 3	Type of Braking System	Additional Comments
Bilevel Coaches	Hyundai Rotem	SCRRA (US)	Bilevel Coaches	Regional	Multi-Level Trailer	Wide Body	112 (180)	112 (180)	N/A	"HRU-1"	Hyundai Rotem	Unpowered	56.5 (1435)	Rubber Chevron	Air Spring Bolster	Inboard	N/A	N/A	N/A	Friction - disc (axle)	
EMU	Hyundai Rotem	SEPTA (US)	Silverliner V	Regional	Single Level EMU	Wide Body	99 (160)	110 (177)	N/A	"HRU-2"	Hyundai Rotem	Both	56.5 (1435)	Rubber Chevron	Air Spring Bolster	Inboard	N/A	N/A	N/A	Friction - disc (axle)	

Table B13. Rubber Metacone/Flexible Frame – Air Spring/Bolster/Center Pivot – Inboard Bearings (v.12.13)

Rubber Metacone/Flexible Frame – Air Spring/Bolster/Center Pivot – Inboard Bearings (v.12.13)

Car/Trainset	Primary Car/Trainset Manufacturer	Owner/Operator	Series Name	Operation	Body Type	Body Width	Car/Trainset Max Operating Speed mph (km/h)	Truck Maximum Speed mph (km/h)	Car/Trainset Weight (Tare) tons (tonnes)	Truck	Truck Manufacturer	Powered/ Unpowered	Gauge in (mm)	Primary Suspension	Secondary Suspension	Bearing Location	Specialized Feature 1	Specialized Feature 2	Specialized Feature 3	Type of Braking System	Additional Comments
Meridian (Voyager)	Bombardier	EMT (UK)	BR Class 222	Intercity	Single Level DMU	Standard Body	124 (200)	124 (200)	N/A	FLEXX Eco	Bombardier	Both	56.5 (1435)	Rubber Metacone Spring Flexible Frame	Air Spring Bolster Center Pivot	Inboard	N/A	N/A	N/A	Dynamic - rheo Friction - disc (cheek) Track brakes (optional)	

Table B14. Equalizer – Swing Hanger – Outboard Bearings (v.12.13)

Equalizer – Swing Hanger – Outboard Bearings (v.12.13)

Car/Trainset	Primary Car/Trainset Manufacturer	Owner/Operator	Series Name	Operation	Body Type	Body Width	Car/Trainset Max Operating Speed mph (km/h)	Truck Maximum Speed mph (km/h)	Car/Trainset Weight (Tare) tons (tonnes)	Truck	Truck Manufacturer	Powered/ Unpowered	Gauge in (mm)	Primary Suspension	Secondary Suspension	Bearing Location	Specialized Feature 1	Specialized Feature 2	Specialized Feature 3	Type of Braking System	Additional Comments
Bilevel Coaches	Nippon Sharyo	VRE (US)	N/A	Regional	Multi-Level Trailer	Standard Body	79 (127)	79 (127)	[1] 63.0 (57.2)	"VRE-1"	Nippon Sharyo	Unpowered	56.5 (1435)	Equalizer	Swing Hanger	Outboard	N/A	N/A	N/A	Friction	This coach was developed jointly with Sumitomo.

Table B15. Equalizer – Air Spring/Bolster/Center Pivot – Inboard Bearings (v.12.13)

Equalizer – Air Spring/Bolster/Center Pivot – Inboard Bearings (v.12.13)

Car/Trainset	Primary Car/Trainset Manufacturer	Owner/Operator	Series Name	Operation	Body Type	Body Width	Car/Trainset Max Operating Speed mph (km/h)	Truck Maximum Speed mph (km/h)	Car/Trainset Weight (Tare) tons (tonnes)	Truck	Truck Manufacturer	Powered/ Unpowered	Gauge in (mm)	Primary Suspension	Secondary Suspension	Bearing Location	Specialized Feature 1	Specialized Feature 2	Specialized Feature 3	Type of Braking System	Additional Comments
Single Level Coaches	Bombardier	NJT (US)	Comet III	Regional	Single Level Trailer	Standard Body	120 (193)	120 (193)	[1] 45 (40.8)	G70-I	GSI	Unpowered	56.5 (1435)	Equalizer	Air Spring Bolster Center Pivot	Inboard	N/A	N/A	N/A	Friction - tread	

Table B16. Equalizer – Coil Spring/Bolster/Center Pivot – Outboard Bearings (v.12.13)

Equalizer – Coil Spring/Bolster/Center Pivot – Outboard Bearings (v.12.13)

Car/Trainset	Primary Car/Trainset Manufacturer	Owner/Operator	Series Name	Operation	Body Type	Body Width	Car/Trainset Max Operating Speed mph (km/h)	Truck Maximum Speed mph (km/h)	Car/Trainset Weight (Tare) tons (tonnes)	Truck	Truck Manufacturer	Powered/ Unpowered	Gauge in (mm)	Primary Suspension	Secondary Suspension	Bearing Location	Specialized Feature 1	Specialized Feature 2	Specialized Feature 3	Type of Braking System	Additional Comments
Bilevel Coaches	Bombardier	Amtrak (US)	Superliner II	Intercity	Multi-Level Trailer	Standard Body	110 (177)	125 (201)	[1] 77.5 (70.3)	G70-O	GSI	Unpowered	56.5 (1435)	Equalizer	Coil Spring Bolster Center Pivot	Outboard	N/A	N/A	N/A	Friction - disc (axle)/tread	
Single Level Coaches	Bombardier	Amtrak (US)	Horizon	Intercity	Single Level Trailer	Standard Body	125 (201)	125 (201)	[1] 58 (52.6)	G70-O	GSI	Unpowered	56.5 (1435)	Equalizer	Coil Spring Bolster Center Pivot	Outboard	N/A	N/A	N/A	Friction	

Appendix C.
Master Candidate List

Table C. Master Candidate List (v.04.13)

Master Candidate List (v.04.13)

Car/Trainset	Primary Car/Trainset Manufacturer	Owner/Operator	Series	Operation	Body	Body Width	Car/Trainset Max Operating	Truck Maximum	Car/Trainset Weight	Truck	Truck Manufacture	Powered/ Unpowered	Gauge in	Primary Suspensi	Secondary	Bearing	Specialized	Specialized	Specialized	Type of Braking	Additional Comments
	Alstom	NTV (Italy)	ETR 575	High Speed	Single Level EMU	Standard Body	186 (300)	224 (360)	[11] 451.9 (410)	"AGV-1"	Alstom	Both	56.5 (1435)	Journal Spring	Air Spring	Outboard	Articulated Cars	N/A	N/A		
Coradia Duplex	Alstom	SNCF (France)	SNCF Class Z 26500	Intercity	Multi-Level EMU	Standard Body	99 (160)	99 (160)	N/A	"COR-1"	Alstom	Both	56.5 (1435)	Journal Spring	Air Spring	Outboard	N/A	N/A	N/A	Dynamic - regen Friction - disc (axle)	Other versions of Coradia are available (e.g. low floor Coradia Continental, DMU Coradia Lint, etc.).
New Pendolino	Alstom	Trenitalia (Italy)	ETR 600	High Speed	Single Level EMU	Standard Body	155 (250)	155 (250)	[7] 426.6 (387)	"PEN-1"	Alstom	Both	56.5 (1435)	Journal Spring	Coil Spring	Outboard	Active Tilt	N/A	N/A	Dynamic Friction - disc (axle)	
New Pendolino	Alstom	MOR (China)	CRH5	High Speed	Single Level EMU	Wide Body	155 (250)	155 (250)	[8] 488.3 (443)	"PEN-2"	Alstom	Both	56.5 (1435)	Journal Spring	Air Spring	Outboard	N/A	N/A	N/A	Dynamic - regen Friction - disc (axle)	Though it is part of the New Pendolino family, the CRH5 is a non-tilting trainset.
IC4	Ansaldo Breda	DSB (Denmark)	DSB Class MG	Intercity	Single Level DMU	Standard Body	124 (200)	124 (200)	[4] 154.3 (140)	"IC4-1"	Ansaldo Breda	Both	56.5 (1435)	Journal Spring	Air Spring Center Pivot	Outboard	Articulated Cars	N/A	N/A	Dynamic Friction - disc (axle) Track brakes	
V250	Ansaldo Breda	NS (Netherlands) SNCB (Belgium)	Fyra	High Speed	Single Level EMU	Standard Body	155 (250)	155 (250)	[8] 466.2 (423)	"250-1"	Ansaldo Breda	Both	56.5 (1435)	Journal Spring	Air Spring	Outboard	N/A	N/A	N/A	Dynamic Friction	
V300 Zefiro	Ansaldo Breda	Trenitalia (Italy)	ETR 1000	High Speed	Single Level EMU	Standard Body	186 (300)	224 (360)	[8] 551.2 (500)	FLEXX Speed	Bombardier	Both	56.5 (1435)	Radial Arm	Airspring	Outboard	N/A	N/A	N/A	Dynamic Friction - disc (m - cheek) Friction - disc (t - axle)	This trainset is being developed jointly with Bombardier.
AGC	Bombardier	SNCF (France)	SNCF Class B 82500	Regional	Single Level Dual	Standard Body	99 (160)	99 (160)	N/A	FLEXX Compact	Bombardier	Both	56.5 (1435)	Journal Spring	Air Spring	Outboard	Articulated Cars	N/A	N/A	Dynamic Friction - disc (cheek)	
Meridian (Voyager)	Bombardier	EMT (UK)	BR Class 222	Intercity	Single Level DMU	Standard Body	124 (200)	124 (200)	N/A	FLEXX Eco	Bombardier	Both	56.5 (1435)	Flexible Frame Rubber Metacone Spring	Air Spring Bolster Center Pivot	Inboard	N/A	N/A	N/A	Dynamic - rheo Friction - disc (cheek) Track brakes (optional)	
Regina	Bombardier	SJ (Sweden)	SJ 3000	Intercity	Single Level EMU	Wide Body	124 (200)	155 (250)	[2] 132.3 (120)	FLEXX Link	Bombardier	Both	56.5 (1435)	Coil Spring/Rubber Radial Arm	Air Spring	Outboard	N/A	N/A	N/A	Dynamic Friction - disc (cheek) Track brakes	
Talent	Bombardier	NSB (Norway)	NSB Class 93	Regional	Single Level DMU	Standard Body	87 (140)	99 (160)	[2] 84.9 (77)	FLEXX Compact	Bombardier	Both	56.5 (1435)	Journal Spring	Air Spring	Outboard	Articulated Cars	Passive Tilt	N/A	Dynamic Friction - disc (cheek)	
Talent 2	Bombardier	DB (Germany)	Class 442 (DB)	Regional	Single Level EMU	Standard Body	99 (160)	99 (160)	N/A	FLEXX Compact	Bombardier	Both	56.5 (1435)	Journal Spring	Air Spring	Outboard	Articulated Cars	N/A	N/A	Dynamic Friction - disc (cheek)	
Twindexx Express	Bombardier	SBB (Switzerland)	SBB RABDe 502	Intercity	Multi-Level Power	Standard Body	124 (200)	143 (230)	[1] 57.3 (52)	FLEXX Tronic WAKO	Bombardier	Powered	56.5 (1435)	Journal Spring	Airspring Bolster	Outboard	Active Radial Steering	Active Tilt	N/A	Dynamic Friction	This car is part of a 656 ft (200 m), 8-car trainset.
Twindexx Express	Bombardier	SBB (Switzerland)	SBB RABDe 502	Intercity	Multi-Level Trailer	Standard Body	124 (200)	143 (230)	[1] 55.1 (50)	FLEXX Tronic WAKO	Bombardier	Unpowered	56.5 (1435)	Journal Spring	Airspring Bolster	Outboard	Active Radial Steering	Active Tilt	N/A	Friction	This car is part of a 656 ft (200 m), 8-car trainset.
Zefiro 380	Bombardier	MOR (China)	CRH380D	High Speed	Single Level EMU	Wide Body	236 (380)	236 (380)	[8] 509.3 (462)	FLEXX Speed	Bombardier	Both	56.5 (1435)	Radial Arm	Air Spring	Outboard	N/A	N/A	N/A	Dynamic Friction - disc (m - cheek) Friction - disc (t - axle)	This trainset is being developed by Bombardier Sifang.
Civity	CAF	Concept	N/A	Regional	Single Level EMU	Standard Body	124 (200)	124 (200)	[3] 110.2 (100)	"CIV-1"	CAF	Both	56.5 (1435)	Journal Spring	Air Spring	Outboard	Articulated Cars	N/A	N/A	Dynamic Friction - disc (cheek)	This trainset is available with electric, mechanical diesel/hydraulic diesel, electric- diesel, or dual tractions. It can be configured as 3, 4, 5, 6, 7, or 8 cars.
Civity Duo	CAF	Concept	N/A	Regional	Multi-Level EMU	Standard Body	124 (200)	124 (200)	N/A	"CIV-2"	CAF	Both	56.5 (1435)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	
Oaris	CAF	Concept	N/A	High Speed	Single Level EMU	Standard Body	218 (350)	218 (350)	N/A	"OAR-1"	CAF	Both	56.5 (1435)	Journal Spring	Air Spring	Outboard	N/A	N/A	N/A	Dynamic Friction - disc (cheek)	
Single Level Coaches	CAF	Amtrak (US)	Viewliner II	Intercity	Single Level Trailer	Standard Body	124 (200)	124 (200)	N/A	"VEW-1"	CAF	Unpowered	56.5 (1435)	Journal Spring	Coil Spring	N/A	N/A	N/A	N/A	Friction	
CRH380A	CSR	MOR (China)	CRH380A	High Speed	Single Level EMU	Wide Body	218 (350)	236 (380)	[8] 529.1 (480)	"380-1"	CSR	Both	56.5 (1435)	Radial Arm	Airspring Bolsterless	Outboard	N/A	N/A	N/A	Dynamic - regen Friction - disc (m/t - cheek) Friction - disc (t - axle) Tread cleaning shoes	
Javelin (A Train High Speed)	Hitachi	LSER (UK)	BR Class 395	High Speed	Single Level EMU	Standard Body	140 (225)	140 (225)	[6] 293.2 (266)	"JAV-1"	Hitachi	Both	56.5 (1435)	Radial Arm	Air Spring Bolsterless	Outboard	N/A	N/A	N/A	Dynamic Friction	The Javelin truck includes equipment to accommodate third-rail operations up to 99 mph (160 km/h).
Bilevel Coaches	Hyundai Rotem	SCRRA (US)	Bilevel Coaches	Regional	Multi-Level Trailer	Wide Body	112 (180)	112 (180)	N/A	"HRU-1"	Hyundai Rotem	Unpowered	56.5 (1435)	Rubber Chevron	Air Spring Bolster	Inboard	N/A	N/A	N/A	Friction - disc (axle)	
EMU	Hyundai Rotem	SEPTA (US)	Silverliner V	Regional	Single Level EMU	Wide Body	99 (160)	110 (177)	N/A	"HRU-2"	Hyundai Rotem	Both	56.5 (1435)	Rubber Chevron	Air Spring Bolster	Inboard	N/A	N/A	N/A	Friction - disc (axle)	
Hanvit 200	Hyundai Rotem	Korail (Korea)	TTX	High Speed	Single Level EMU	Standard Body	112 (180)	124 (200)	[6] 379.2 (344)	"HAN-1"	Hyundai Rotem	Both	56.5 (1435)	Journal Spring	Air Spring Bolster	Outboard	Active Radial Steering	Active Tilt	N/A	Dynamic - regen Friction - disc (cheek)	
HEMU-430X	Hyundai Rotem	Korail (Korea)	KTX III	High Speed	Single Level EMU	Standard Body	230 (370)	249 (400)	N/A	"430-1"	Hyundai Rotem	Both	56.5 (1435)	Radial Arm	Air Spring Center Pivot	Outboard	N/A	N/A	N/A	Dynamic Friction - disc (cheek)	This trainset was previously known as the HEMU-400X.
E5 Series	Kawasaki	JR East (Japan)	Hayabusa	High Speed	Single Level EMU	Wide Body	199 (320)	224 (360)	[10] 500.8 (454.3)	DT209 TR700 8	Kawasaki	Both	56.5 (1435)	Leaf Spring	Air Spring Bolsterles s	Outboard	Active Tilt	N/A	N/A	Dynamic - regen Friction - disc (cheek) Tread cleaning shoes	This trainset can also be provided by Hitachi.
efSET	Kawasaki	Concept	N/A	High Speed	Single Level EMU	Wide Body	218 (350)	218 (350)	[8] 496.0 (450)	"EFS-1"	Kawasaki	Both	56.5 (1435)	Radial Arm	Air Spring Bolsterless	Outboard	Active Tilt	N/A	N/A	Dynamic - regen Friction - disc (cheek)	The efSET is still a conceptual design.
N700 Series	Kawasaki	JR Central (Japan) JR Kyushu (Japan) JR West (Japan)	Nozomi	High Speed	Single Level EMU	Wide Body	186 (300)	186 (300)	[14] 788.2 (715)	"N70-1"	Kawasaki	Both	56.5 (1435)	Radial Arm	Air Spring Bolsterles s	Outboard	Active Tilt	N/A	N/A	Dynamic - regen Friction - disc (cheek) Tread cleaning shoes	This trainset can also be provided by Hitachi, Nippon Sharyo, and Kinki Sharyo.
Bilevel Coaches	Nippon Sharyo	VRE (US)	N/A	Regional	Multi-Level Trailer	Standard Body	79 (127)	79 (127)	[1] 63.0 (57.2)	"VRE-1"	Nippon Sharyo	Unpowered	56.5 (1435)	Equalizer	Swing Hanger	Outboard	N/A	N/A	N/A	Friction	This coach was developed jointly with Sumitomo.
DMU	Nippon Sharyo	SMART (US)	N/A	Regional	Single Level DMU	Wide Body	79 (127)	79 (127)	[1] 80.3 (73)	"SMT-1"	Nippon Sharyo	Both	56.5 (1435)	N/A	N/A	N/A	N/A	N/A	N/A	Dynamic - regen Friction	Information presented is based on SMART DMU specification for industry. This DMU is being developed jointly with Sumitomo.
Desiro City	Siemens	Concept - TRSP	N/A	Regional	Single Level Power	Standard Body	99 (160)	99 (160)	N/A	"DES-1"	Siemens	Powered	56.5 (1435)	N/A	Air Spring	Inboard	N/A	N/A	N/A	Dynamic - rheo	The Desiro City is still a conceptual design.
Desiro City	Siemens	Concept - TRSP	N/A	Regional	Single Level Trailer	Standard Body	99 (160)	99 (160)	N/A	"DES-2"	Siemens	Unpowered	56.5 (1435)	N/A	Air Spring	Inboard	N/A	N/A	N/A	Friction - disc (axle)	The Desiro City is still a conceptual design.
Desiro Classic	Siemens	NCTD (US)	Sprinter	Regional	Single Level DMU	Standard Body	75 (120)	75 (120)	[2] 77.2 (70)	SF 4000 TDG SF 4000 JLDG	Siemens	Both	56.5 (1435)	Metal-Rubber Conical Sleeve Springs	Air Spring Bolster Center Pivot	Outboard	N/A	N/A	N/A	Friction - disc (m - axle) Friction - disc (t - cheek) Track brakes (m - optional)	
Desiro Double Deck	Siemens	SBB (Switzerland)	SBB RABe 514	Regional	Multi-Level EMU	Standard Body	(140)	87 (140)	[4] 240.3 (218)	SF 500 DSW	Siemens	Powered	56.5 (1435)	Radial Arm	Air Spring Bolster Center Pivot	Outboard	Passive Steering	N/A	N/A	Dynamic Friction - disc (cheek)	
Desiro Double Deck	Siemens	SBB (Switzerland)	SBB RABe 514	Regional	Multi-Level EMU	Standard Body	87 (140)	174 (280)	[4] 240.3 (218)	SF 400	Siemens	Unpowered	56.5 (1435)	Flexible Frame Journal Spring	Air Spring Center Pivot	Outboard	Passive Steering	N/A	N/A	Friction - disc (axle)	The information shown is for the SF 400 truck. It is expected that there is a version of this truck that accommodates double-deck coaches (i.e. SF 400 DSW).
Desiro EMU	Siemens	OSE (Greece)	OSE Class 460	Regional	Single Level EMU	Standard Body	99 (160)	124 (200)	[5] 165.4 (150)	SF 5000 E TDG SF 5000 LDG SF 5000 JTDG SF 5000 JLDG	Siemens	Both	56.5 (1435)	Radial Arm	Air Spring Bolster/Bolsterles s	Outboard	Passive Steering	N/A	N/A	Dynamic Friction - disc (cheek)	
Desiro ML	Siemens	Transregio (Germany) SNCB (Belgium) OBB (Austria)	Class 460 (Transregio)	Regional	Single Level EMU	Standard Body	99 (160)	99 (160)	[3] 145.5 (132)	SF 6500 TDG SF 6500 LDG	Siemens	Both	56.5 (1435)	Journal Spring	Air Spring Center Pivot	Outboard	Passive Steering	N/A	N/A	Dynamic Friction - disc (cheek) Track brakes (optional)	The Desiro ML trainset is also available as a DMU.

Master Candidate List (v.04.13)

ICE TD (Venturio)	Siemens	DB (Germany) DSB (Denmark)																			
ICx	Siemens	DB (Germany)																			
															Air Spring Bolster Center Pivot	Inboard	N/A	N/A	N/A	Friction - disc (cheek) Electromagnetic track brake	The ICx consists of self-contained motor and trailer cars. The maximum speed shown is for a 656 ft (200 m), 7-car trainset, which includes 3 motored cars. The ICx trailer truck will be Bombardier's FLEXX Eco truck. It is anticipated that the truck will be designed to accommodate the higher operational speed.
Velaro CN	Siemens	MOR (China)	CRH3C	High Speed	Single Level EMU	Wide Body	218 (350)	218 (350)	[8] 492.7 (447)	SF 500 TDG SF 500 LDG	Siemens	Both	56.5 (1435)	Flexible Frame Radial Arm	Air Spring Bolster/Bolsterles s Center Pivot	Outboard	Passive Steering	N/A	N/A	Dynamic - regen/rheo Friction - disc (m - cheek) Friction - disc (t - axle)	This trainset can also be provided by CNR.
Velaro D	Siemens	DB (Germany)	Class 407	High Speed	Single Level EMU	Standard Body	199 (320)	218 (350)	[8] 500.5 (454)	SF 500 TDG SF 500 LDG	Siemens	Both	56.5 (1435)	Flexible Frame Radial Arm	Air Spring Bolster/Bolsterles s Center Pivot	Outboard	Passive Steering	N/A	N/A	Dynamic - regen/rheo Friction - disc (m - cheek) Friction - disc (t - axle)	
Viaggio Comfort	Siemens	OBB (Austria) CD (Czech)	Railjet (OBB)	Intercity	Single Level Trailer	Standard Body	155 (250)	174 (280)	[1] 52.9 (48)	SF 400	Siemens	Unpowered	56.5 (1435)	Flexible Frame Journal Spring	Air Spring Center Pivot	Outboard	Passive Steering	N/A	N/A	Friction - disc (axle) Electromagnetic track brake	
Viaggio Light	Siemens	ISR (Israel)	SDPP	Regional	Single Level Trailer	Standard Body	99 (160)	124 (200)	[1] 47.4 (43)	SF 300	Siemens	Unpowered	56.5 (1435)	Flexible Frame Journal Spring	Coil Spring Bolster Center Pivot	Outboard	Passive Steering	N/A	N/A	Friction - disc (axle) Electromagnetic track brake	
FLIRT EMU	Stadler	SBB (Switzerland)	SBB RABe 523	Regional	Single Level EMU	Standard Body	99 (160)	99 (160)	[4] 132.3 (120)	"FLI-1" "FLI-2"	Stadler/LRS	Both	56.5 (1435)	Journal Spring	Air Spring	Outboard	Articulated Cars	N/A	N/A	Dynamic - regen/rheo Friction - disc (cheek)	Stadler's FLIRTs are also available as DMUs. The most recent trainsets (e.g. EMUs/DMUs for Elektriraudtee (Estonia) and the FLIRT EMU 3 for Veolia (Germany) have trucks of different wheelbases and wheel diameters.
GTW DMU-2 2/6	Stadler	DCTA (US)	A-Train	Regional	Single Level DMU	Standard Body	75 (120)	99 (160)	[3] 80.0 (72.2)	"GTW-1" "GTW-2"	Stadler/LRS	Both	56.5 (1435)	Journal Spring	Air Spring	Outboard	Articulated Cars	N/A	N/A	Dynamic Friction - disc (cheek/axle)	

Appendix D.
Truck Information

Figure D1. Bombardier BOM-1 Motor

Manufacturer	Bombardier	
Truck	"BOM-1"	Motor
Running Speed [mph (km/h)]	99 (160)	
Axle Load [tons (tonnes)]	N/A	
Wheelbase [in (mm)]	102 (2591)	
Wheel diameter new [in (mm)]	36 (915)	
Wheel diameter worn [in (mm)]	N/A	
Minimum curve radius - service [ft (m)]	N/A	
Minimum curve radius - shop [ft (m)]	N/A	
Truck height [in (mm)]	N/A	
Weight - powered [tons (tonnes)]	11.7 (10.6)	
Weight - unpowered [tons (tonnes)]	N/A	

Figure D2. CAF CIV-1 Motor and Trailer

Manufacturer	CAF	
Truck	“CIV-1”	Motor and Trailer
Running Speed [mph (km/h)]	124 (200)	
Axle Load [tons (tonnes)]	N/A	
Wheelbase [in (mm)]	N/A	
Wheel diameter new [in (mm)]	33.5 (850)	
Wheel diameter worn [in (mm)]	N/A	
Minimum curve radius - service [ft (m)]	N/A	
Minimum curve radius - shop [ft (m)]	N/A	
Truck height [in (mm)]	N/A	
Weight - powered [tons (tonnes)]	N/A	
Weight - unpowered [tons (tonnes)]	N/A	

Figure D3. Alstom COR-1 Motor and Trailer

Manufacturer	Alstom	
Truck	“COR-1”	Motor and trailer
Running Speed [mph (km/h)]	99 (160)	
Axle Load [tons (tonnes)]	N/A	
Wheelbase [in (mm)]	N/A	
Wheel diameter new [in (mm)]	33.5 (850)	
Wheel diameter worn [in (mm)]	N/A	
Minimum curve radius - service [ft (m)]	N/A	
Minimum curve radius - shop [ft (m)]	N/A	
Truck height [in (mm)]	N/A	
Weight - powered [tons (tonnes)]	N/A	
Weight - unpowered [tons (tonnes)]	N/A	

Figure D4. Bombardier FLEXX Compact Motor and Trailer Bogies

Manufacturer	Bombardier	
Truck	FLEXX Compact Motor and trailer bogies (Jacobs-type for latter)	
Running Speed [mph (km/h)]	99 (160)	
Axle Load [tons (tonnes)]	N/A	
Wheelbase [in (mm)]	N/A	
Wheel diameter new [in (mm)]	N/A	
Wheel diameter worn [in (mm)]	N/A	
Minimum curve radius - service [ft (m)]	N/A	
Minimum curve radius - shop [ft (m)]	N/A	
Truck height [in (mm)]	34.2 (615)	Based on height above air spring for the Talent DMU
Weight - powered [tons (tonnes)]	N/A	
Weight - unpowered [tons (tonnes)]	N/A	

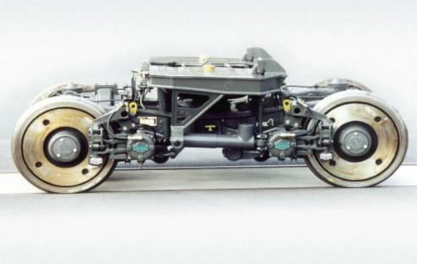

Figure D5. Bombardier FLEXX Eco B5000 / Motor and Trailer

Manufacturer	Bombardier	
Truck	FLEXX Eco	Previously designated B5000 / motor and trailers
Running Speed [mph (km/h)]	124 (200)	Ranges from 99 (160) to 124 (200)
Axle Load [tons (tonnes)]	17.1 (15.5)	Ranges from (13.6) to 17.1 (15.5)
Wheelbase [in (mm)]	98.4 (2500)	Ranges from 88.6 (2250) to 98.4 (2500)
Wheel diameter new [in (mm)]	30.7 (780)	
Wheel diameter worn [in (mm)]	N/A	
Minimum curve radius - service [ft (m)]	N/A	
Minimum curve radius - shop [ft (m)]	N/A	
Truck height [in (mm)]	37.8 (960)	Height over secondary suspension. Ranges from (900) to 37.8 (960).
Weight - powered [tons (tonnes)]	N/A	
Weight - unpowered [tons (tonnes)]	5.1 (4.6)	Weight is with center pivot and interface bolster

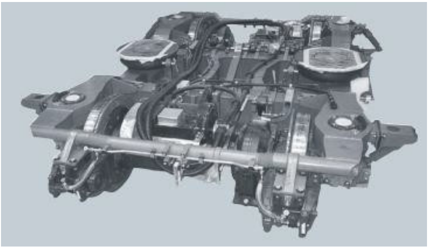

Figure D6. Bombardier FLEXX Link Motor and Trailer

Manufacturer	Bombardier	
Truck	FLEXX Link	Motor and Trailer
Running Speed [mph (km/h)]	155 (250)	
Axle Load [tons (tonnes)]	20.4 (18.5)	
Wheelbase [in (mm)]	106.3 (2700)	
Wheel diameter new [in (mm)]	36.0 (915)	
Wheel diameter worn [in (mm)]	32.9 (835)	
Minimum curve radius - service [ft (m)]	N/A	
Minimum curve radius - shop [ft (m)]	N/A	
Truck height [in (mm)]	33.3 (843)	Height over secondary suspension
Weight - powered [tons (tonnes)]	9.0 (8.2)	
Weight - unpowered [tons (tonnes)]	7.2 (6.5)	

Figure D7. Bombardier FLEXX Tronic and WAKO (motor and trailer)

Manufacturer	Bombardier	
Truck	FLEXX Tronic	FLEXX Tronic WAKO (motor and trailer)
Running Speed [mph (km/h)]	143 (230)	
Axle Load [tons (tonnes)]	20.2 (18.3)	
Wheelbase [in (mm)]	94.5 (2400)	
Wheel diameter new [in (mm)]	N/A	
Wheel diameter worn [in (mm)]	N/A	
Minimum curve radius - service [ft (m)]	N/A	
Minimum curve radius - shop [ft (m)]	N/A	
Truck height [in (mm)]	N/A	
Weight - powered [tons (tonnes)]	N/A	
Weight - unpowered [tons (tonnes)]	N/A	

Figure D8. Stadler/LRS Motor

Manufacturer	Stadler/LRS	
Truck	"FLI-1"	Motor
Running Speed [mph (km/h)]	99 (160)	
Axle Load [tons (tonnes)]	22.1 (20)	
Wheelbase [in (mm)]	106.3 (2700)	
Wheel diameter new [in (mm)]	33.9 (860)	
Wheel diameter worn [in (mm)]	31.5 (800)	
Minimum curve radius - service [ft (m)]	N/A	
Minimum curve radius - shop [ft (m)]	N/A	
Truck height [in (mm)]	N/A	
Weight - powered [tons (tonnes)]	N/A	
Weight - unpowered [tons (tonnes)]	N/A	

Figure D9. Stadler/LRS Trailer

Manufacturer	Stadler/LRS	
Truck	"FLI-2"	Trailer
Running Speed [mph (km/h)]	99 (160)	
Axle Load [tons (tonnes)]	18.7 (17)	
Wheelbase [in (mm)]	106.3 (2700)	
Wheel diameter new [in (mm)]	29.5 (750)	
Wheel diameter worn [in (mm)]	27.2 (690)	
Minimum curve radius - service [ft (m)]	N/A	
Minimum curve radius - shop [ft (m)]	N/A	
Truck height [in (mm)]	N/A	
Weight - powered [tons (tonnes)]	N/A	
Weight - unpowered [tons (tonnes)]	N/A	

Figure D10. GSI G70-I Trailer

Manufacturer	GSI	
Truck	G70-I	Trailer
Running Speed [mph (km/h)]	120 (193)	
Axle Load [tons (tonnes)]	N/A	
Wheelbase [in (mm)]	102 (2591)	
Wheel diameter new [in (mm)]	32 (814)	
Wheel diameter worn [in (mm)]	N/A	
Minimum curve radius - service [ft (m)]	N/A	
Minimum curve radius - shop [ft (m)]	N/A	
Truck height [in (mm)]	N/A	
Weight - powered [tons (tonnes)]	N/A	
Weight - unpowered [tons (tonnes)]	6.1 (5.5)	

Figure D11. GSI G70-O Trailer

Manufacturer	GSI	
Truck	G70-O	Trailer
Running Speed [mph (km/h)]	125 (201)	
Axle Load [tons (tonnes)]	N/A	
Wheelbase [in (mm)]	102 (2591)	
Wheel diameter new [in (mm)]	36 (915)	
Wheel diameter worn [in (mm)]	N/A	
Minimum curve radius - service [ft (m)]	N/A	
Minimum curve radius - shop [ft (m)]	250 (76)	
Truck height [in (mm)]	N/A	
Weight - powered [tons (tonnes)]	N/A	
Weight - unpowered [tons (tonnes)]	11.0 (10)	

Figure D12. Stadler/LRS GTW-1 Motor

Manufacturer	Stadler/LRS	
Truck	"GTW-1"	Motor
Running Speed [mph (km/h)]	99 (160)	
Axle Load [tons (tonnes)]	22.1 (20)	
Wheelbase [in (mm)]	82.7 (2100)	
Wheel diameter new [in (mm)]	33.9 (860)	
Wheel diameter worn [in (mm)]	31.5 (800)	
Minimum curve radius - service [ft (m)]	N/A	
Minimum curve radius - shop [ft (m)]	N/A	
Truck height [in (mm)]	N/A	
Weight - powered [tons (tonnes)]	N/A	
Weight - unpowered [tons (tonnes)]	N/A	

Figure D13. Stadler/LRS GTW-2 Trailer

Manufacturer	Stadler/LRS	
Truck	"GTW-2"	Trailer
Running Speed [mph (km/h)]	99 (160)	
Axle Load [tons (tonnes)]	16.5 (15)	
Wheelbase [in (mm)]	82.7 (2100)	
Wheel diameter new [in (mm)]	29.5 (750)	
Wheel diameter worn [in (mm)]	27.2 (690)	
Minimum curve radius - service [ft (m)]	N/A	
Minimum curve radius - shop [ft (m)]	N/A	
Truck height [in (mm)]	N/A	
Weight - powered [tons (tonnes)]	N/A	
Weight - unpowered [tons (tonnes)]	N/A	

Figure D14. Hyundai Rotem HAN-1 Motor and Trailer

Manufacturer	Hyundai Rotem	
Truck	"HAN-1"	Motor and Trailer
Running Speed [mph (km/h)]	124 (200)	
Axle Load [tons (tonnes)]	16.5 (15)	
Wheelbase [in (mm)]	N/A	
Wheel diameter new [in (mm)]	N/A	
Wheel diameter worn [in (mm)]	N/A	
Minimum curve radius - service [ft (m)]	N/A	
Minimum curve radius - shop [ft (m)]	N/A	
Truck height [in (mm)]	N/A	
Weight - powered [tons (tonnes)]	N/A	
Weight - unpowered [tons (tonnes)]	N/A	

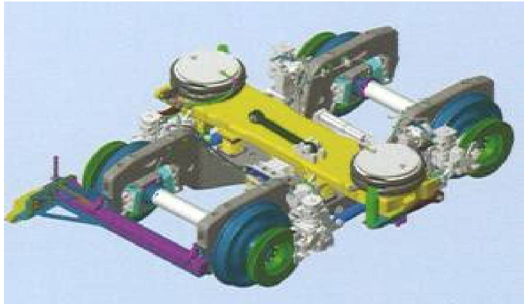

Figure D15. Hyundai Rotem HRU-1 Trailer

Manufacturer	Hyundai Rotem	
Truck	"HRU-1"	Trailer
Running Speed [mph (km/h)]	112 (180)	
Axle Load [tons (tonnes)]	N/A	
Wheelbase [in (mm)]	102 (2591)	
Wheel diameter new [in (mm)]	33 (838)	
Wheel diameter worn [in (mm)]	N/A	
Minimum curve radius - service [ft (m)]	N/A	
Minimum curve radius - shop [ft (m)]	N/A	
Truck height [in (mm)]	N/A	
Weight - powered [tons (tonnes)]	N/A	
Weight - unpowered [tons (tonnes)]	8.4 (7.6)	

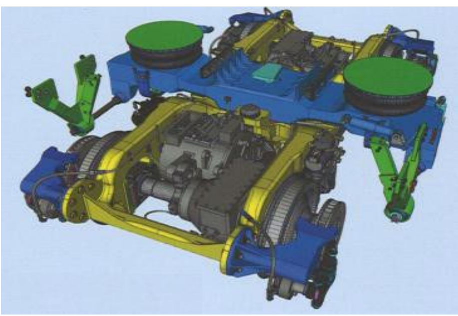

Figure D16. Hyundai Rotem HRU-2 Motor and Trailer

Manufacturer	Hyundai Rotem	
Truck	"HRU-2"	Motor and Trailer
Running Speed [mph (km/h)]	110 (177)	
Axle Load [tons (tonnes)]	N/A	
Wheelbase [in (mm)]	102 (2591)	
Wheel diameter new [in (mm)]	32 (813)	
Wheel diameter worn [in (mm)]	N/A	
Minimum curve radius - service [ft (m)]	N/A	
Minimum curve radius - shop [ft (m)]	N/A	
Truck height [in (mm)]	N/A	
Weight - powered [tons (tonnes)]	11.3 (10.2)	
Weight - unpowered [tons (tonnes)]	N/A	

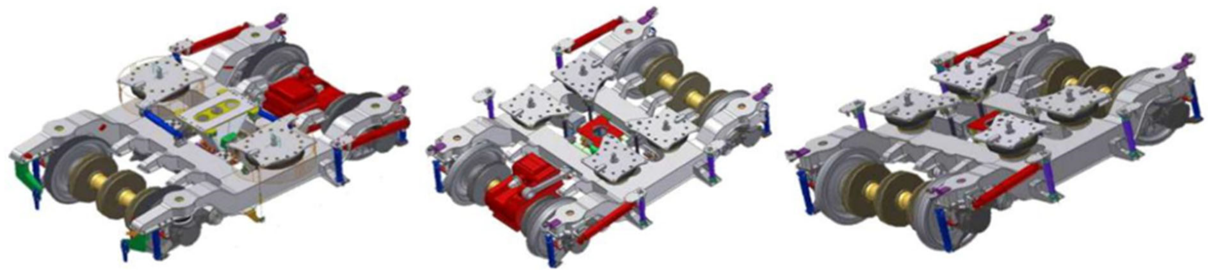

Figure D17. Ansaldo Breda ICA-1 (left) End Motor, (middle) Intermediate Motor (right) Intermediate Trailer

Manufacturer	Ansaldo Breda	
Truck	"IC4-1"	End motor, intermediate motor, and intermediate trailer
Running Speed [mph (km/h)]	124 (200)	
Axle Load [tons (tonnes)]	23.5 (21.3)	
Wheelbase [in (mm)]	110.2 (2800)	
Wheel diameter new [in (mm)]	33.9 (860)	
Wheel diameter worn [in (mm)]	31.5 (800)	
Minimum curve radius - service [ft (m)]	N/A	
Minimum curve radius - shop [ft (m)]	N/A	
Truck height [in (mm)]	N/A	
Weight - powered [tons (tonnes)]	N/A	
Weight - unpowered [tons (tonnes)]	N/A	

Figure D18. Kawasaki KAW-1 Trailer

Manufacturer	Kawasaki	
Truck	"KAW-1"	Trailer
Running Speed [mph (km/h)]	99 (160)	
Axle Load [tons (tonnes)]	N/A	
Wheelbase [in (mm)]	96 (2438)	
Wheel diameter new [in (mm)]	36 (915)	
Wheel diameter worn [in (mm)]		
Minimum curve radius - service [ft (m)]	N/A	
Minimum curve radius - shop [ft (m)]	N/A	
Truck height [in (mm)]	N/A	
Weight - powered [tons (tonnes)]	N/A	
Weight - unpowered [tons (tonnes)]	N/A	

Figure D19. Kawasaki KAW-2 Trailer

Manufacturer	Kawasaki	
Truck	"KAW-2"	Trailer
Running Speed [mph (km/h)]	87 (140)	
Axle Load [tons (tonnes)]	N/A	
Wheelbase [in (mm)]	102 (2591)	
Wheel diameter new [in (mm)]	36 (915)	
Wheel diameter worn [in (mm)]	N/A	
Minimum curve radius - service [ft (m)]	N/A	
Minimum curve radius - shop [ft (m)]	N/A	
Truck height [in (mm)]	N/A	
Weight - powered [tons (tonnes)]	N/A	
Weight - unpowered [tons (tonnes)]	8.3 (7.6)	

Figure D20. Kawasaki KAW-3 Motor

Manufacturer	Kawasaki	
Truck	"KAW-3"	Motor
Running Speed [mph (km/h)]	99 (160)	
Axle Load [tons (tonnes)]	N/A	
Wheelbase [in (mm)]	N/A	
Wheel diameter new [in (mm)]	N/A	
Wheel diameter worn [in (mm)]	N/A	
Minimum curve radius - service [ft (m)]	N/A	
Minimum curve radius - shop [ft (m)]	N/A	
Truck height [in (mm)]	N/A	
Weight - powered [tons (tonnes)]	N/A	
Weight - unpowered [tons (tonnes)]	N/A	

Figure D21. Stadler KIS-1 Motor and Trailer

Manufacturer	Stadler	
Truck	"KIS-1"	Motor and Trailer
Running Speed [mph (km/h)]	99 (160)	
Axle Load [tons (tonnes)]	N/A	
Wheelbase [in (mm)]	98.4 (2500)	
Wheel diameter new [in (mm)]	36.2 (920)	
Wheel diameter worn [in (mm)]	N/A	
Minimum curve radius - service [ft (m)]	N/A	
Minimum curve radius - shop [ft (m)]	N/A	
Truck height [in (mm)]	N/A	
Weight - powered [tons (tonnes)]	N/A	
Weight - unpowered [tons (tonnes)]	N/A	

Figure D22. Nippon Sharyo NT 319 Trailer

Manufacturer	Nippon Sharyo	
Truck	NT 319	Trailer
Running Speed [mph (km/h)]	124 (200)	
Axle Load [tons (tonnes)]	N/A	
Wheelbase [in (mm)]	98.4 (2500)	
Wheel diameter new [in (mm)]	36 (915)	
Wheel diameter worn [in (mm)]	N/A	
Minimum curve radius - service [ft (m)]	N/A	
Minimum curve radius - shop [ft (m)]	N/A	
Truck height [in (mm)]	N/A	
Weight - powered [tons (tonnes)]	N/A	
Weight - unpowered [tons (tonnes)]	7.7 (7.0)	

Figure D23. Siemens SF 300 Trailer

Manufacturer	Siemens	
Truck	SF 300	Trailer
Running Speed [mph (km/h)]	124 (200)	
Axle Load [tons (tonnes)]	17.6 (16)	
Wheelbase [in (mm)]	98.4 (2500)	
Wheel diameter new [in (mm)]	36.2 (920)	
Wheel diameter worn [in (mm)]	33.9 (860)	
Minimum curve radius - service [ft (m)]	492.1 (150)	
Minimum curve radius - shop [ft (m)]	262.5 (80)	
Truck height [in (mm)]	39.1 (994)	
Weight - powered [tons (tonnes)]	N/A	
Weight - unpowered [tons (tonnes)]	7.8 (7.1)	Weight includes the track brake

Figure D24. Siemens SF 400 Trailer

Manufacturer	Siemens	
Truck	SF 400	Trailer
Running Speed [mph (km/h)]	174 (280)	
Axle Load [tons (tonnes)]	18.7 (17)	
Wheelbase [in (mm)]	98.4 (2500)	
Wheel diameter new [in (mm)]	36.2 (920)	
Wheel diameter worn [in (mm)]	N/A	
Minimum curve radius - service [ft (m)]	492.1 (150)	
Minimum curve radius - shop [ft (m)]	262.5 (80)	
Truck height [in (mm)]	38.9 (989)	
Weight - powered [tons (tonnes)]	N/A	
Weight - unpowered [tons (tonnes)]	7.8 (7.1)	Weight includes the track brake

Figure D25. Siemens SF 500 DSW Motor

Manufacturer	Siemens	
Truck	SF 500	SF 500 DSW (motor)
Running Speed [mph (km/h)]	87 (140)	
Axle Load [tons (tonnes)]	22.1 (20)	
Wheelbase [in (mm)]	98.4 (2500)	
Wheel diameter new [in (mm)]	36.2 (920)	
Wheel diameter worn [in (mm)]	33.9 (860)	
Minimum curve radius - service [ft (m)]	492.1 (150)	
Minimum curve radius - shop [ft (m)]	328.1 (100)	
Truck height [in (mm)]	39.8 (1010)	
Weight - powered [tons (tonnes)]	11.9 (10.8)	Weight is with center pivot and bolster
Weight - unpowered [tons (tonnes)]	N/A	

Figure D26. Siemens SF 600 TDG Motor and LDG Trailer

Manufacturer	Siemens	
Truck	SF 600	SF 600 TDG (motor) and LDG (trailer)
Running Speed [mph (km/h)]	155 (250)	
Axle Load [tons (tonnes)]	18.7 (17)	
Wheelbase [in (mm)]	102.4 (2600)	
Wheel diameter new [in (mm)]	33.9 (860)	
Wheel diameter worn [in (mm)]	31.1 (790)	
Minimum curve radius - service [ft (m)]	492.1 (150)	
Minimum curve radius - shop [ft (m)]	N/A	
Truck height [in (mm)]	40.6 (1032)	Height inclusive of bolster
Weight - powered [tons (tonnes)]	9.9 (9)	
Weight - unpowered [tons (tonnes)]	7.7 (7)	

Figure D27. Siemens SF 4000 TDG Motor

Manufacturer	Siemens	
Truck	SF 4000	SF 4000 TDG (motor)
Running Speed [mph (km/h)]	75 (120)	
Axle Load [tons (tonnes)]	16.5 (15)	
Wheelbase [in (mm)]	74.8 (1900)	
Wheel diameter new [in (mm)]	30.3 (770)	
Wheel diameter worn [in (mm)]	30.0 (710)	
Minimum curve radius - service [ft (m)]	410.1 (125)	
Minimum curve radius - shop [ft (m)]	295.3 (90)	
Truck height [in (mm)]	39.3 (997)	Height includes bolster
Weight - powered [tons (tonnes)]	7.5 (6.8)	
Weight - unpowered [tons (tonnes)]	N/A	

Figure D28. Siemens SF 4000 JLDG Trailer

Manufacturer	Siemens	
Truck	SF 4000	SF 4000 JLDG (trailer)
Running Speed [mph (km/h)]	75 (120)	
Axle Load [tons (tonnes)]	17.6 (16)	
Wheelbase [in (mm)]	104.3 (2650)	
Wheel diameter new [in (mm)]	30.3 (770)	
Wheel diameter worn [in (mm)]	30.0 (710)	
Minimum curve radius - service [ft (m)]	410.1 (125)	
Minimum curve radius - shop [ft (m)]	295.3 (90)	
Truck height [in (mm)]	36.7 (931)	Height includes auxiliary air reservoirs
Weight - powered [tons (tonnes)]	N/A	
Weight - unpowered [tons (tonnes)]	6.8 (6.2)	

Figure D29. Siemens SF 5000 E TDG Motor and LDG Trailer

Manufacturer	Siemens	
Truck	SF 5000	SF 5000 E TDG (motor) and LDG (trailer)
Running Speed [mph (km/h)]	124 (200)	
Axle Load [tons (tonnes)]	20.4 (18.5)	
Wheelbase [in (mm)]	102.4 (2600)	
Wheel diameter new [in (mm)]	33.5 (850)	
Wheel diameter worn [in (mm)]	30.3 (770)	
Minimum curve radius - service [ft (m)]	492 (150)	
Minimum curve radius - shop [ft (m)]	328 (100)	
Truck height [in (mm)]	36.0 (915)	Height with bolster
Weight - powered [tons (tonnes)]	9.0 (8.2)	
Weight - unpowered [tons (tonnes)]	6.4 (5.8)	

Figure D30. Siemens SF 5000 JTDG Motor and JLDG Trailer

Manufacturer	Siemens	
Truck	SF 5000	SF 5000 JTDG (motor) and JLDG (trailer)
Running Speed [mph (km/h)]	124 (200)	
Axle Load [tons (tonnes)]	20.4 (18.5)	
Wheelbase [in (mm)]	110.2 (2800)	
Wheel diameter new [in (mm)]	33.5 (850)	
Wheel diameter worn [in (mm)]	30.3 (770)	
Minimum curve radius - service [ft (m)]	492 (150)	
Minimum curve radius - shop [ft (m)]	328 (100)	
Truck height [in (mm)]	36.5 (928)	Height of connection to carbody (with auxiliary air reservoir)
Weight - powered [tons (tonnes)]	10.0 (9.1)	Bogie height (without auxiliary air reservoir)
Weight - unpowered [tons (tonnes)]	7.5 (6.8)	Bogie height (without auxiliary air reservoir)

Figure D31. Siemens SF 65000 TDG Motor and LDG Trailer

Manufacturer	Siemens	
Truck	SF 6500	SF 6500 TDG (motor) and LDG (trailer)
Running Speed [mph (km/h)]	99 (160)	
Axle Load [tons (tonnes)]	19.8 (18)	
Wheelbase [in (mm)]	90.6 (2300)	
Wheel diameter new [in (mm)]	33.5 (850)	
Wheel diameter worn [in (mm)]	30.7 (780)	
Minimum curve radius - service [ft (m)]	360.9 (110)	
Minimum curve radius - shop [ft (m)]	262.5 (80)	
Truck height [in (mm)]	31.5 (800)	Height to top of air spring
Weight - powered [tons (tonnes)]	9.9 (9)	
Weight - unpowered [tons (tonnes)]	7.4 (6.7)	

Figure D32. Nippon Sharyo VRE-1 Trailer

Manufacturer	Nippon Sharyo	
Truck	"VRE-1"	Trailer
Running Speed [mph (km/h)]	79 (127)	
Axle Load [tons (tonnes)]	N/A	
Wheelbase [in (mm)]	102 (2591)	
Wheel diameter new [in (mm)]	33 (838)	
Wheel diameter worn [in (mm)]	N/A	
Minimum curve radius - service [ft (m)]	250 (76)	
Minimum curve radius - shop [ft (m)]	N/A	
Truck height [in (mm)]	N/A	
Weight - powered [tons (tonnes)]	N/A	
Weight - unpowered [tons (tonnes)]	N/A	

Appendix E.
Request for Information to Carbuilders

TTCI® Transportation Technology Center, Inc.

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Addressee Title Company Street Address

City, State, Zip

RE: Request for Information, FRA Task Order 325

To Whom It May Concern,

The Transportation Technology Center, Inc. (TTCI) is performing a research project for the Federal Railroad Administration (FRA): FRA T.O. 325, *Design Considerations for High-Speed Trucks on Passenger Vehicles.* This letter and the accompanying material are intended to clarify the purpose of a request for data and information of your passenger car truck designs.

The FRA has identified a need to research high-speed truck performance in mixed operations. Shared right-of-way operation is a different and demanding service environment for both vehicles and track. With mixed operations, track is subjected to a much wider range of operating conditions, for example speed, wheel load, wheel profile, and truck suspension characteristics. Likewise, rolling stock of all types must perform well within the "best compromise" track design and maintenance requirements. This represents a systems optimization challenge. Design and maintenance of track needs to address passenger and freight operations while ensuring safety and ride quality. Designs of rolling stock need to take into account the track geometry optimized for shared operations and the load environment. This research project is intended to addresses the steps in refining the passenger truck design parameters to assure optimized operation in a mixed traffic environment, develop general guidelines for high-speed passenger trucks for use in shared operations, and to identify one or more potentially useable trucks for use in the North American context. The focus of this study is on designs for operation up to 125 mph.

There is a history of work in this area. A 1996 study by Bing et. al., *Design Data on Suspension Systems of Selected Rail Passenger Cars* compiled data for the U.S. fleet of railroad passenger vehicles. That particular study described the then-current mix of rail passenger equipment in service and identified the characteristics of each for use in numerical modeling. It also aided in identifying car and truck designs not previously used in the US. Recently, some car and truck designs that have been newly introduced that encountered operational challenges or track conditions that were not considered in the original design. Engineering analyses and tests were then required to identify and resolve such challenges and also to ensure that safety and performance goals were being met. A major aspect of this project is therefore to perform mathematical simulations of vehicle dynamic performance including parametric variations to understand the effects of different suspension designs and vehicle parameters on vehicle dynamic response.

One of the initial requirements of this research project is to conduct an industry review of existing passenger truck/bogie designs. TTCI contracted with Parsons Brinckerhoff, Inc. (PBI) to survey the industry and consult with stakeholders to identify, categorize and analyze the state-of-the-art in high-speed truck technologies from around the world. The primary emphasis of this work will be on anticipated vehicle dynamic performance, but supplements will address the current braking and bearing technologies in use. A large amount of this initial effort has already been completed from information readily available primarily through internet searches, but additional information and data are required for use in vehicle dynamics modeling for the most relevant truck types, similar to what was conducted in the 1996 study.

PBI has generated a matrix of high-speed truck candidates listing general information of various truck/car/trainset technologies. In order for TTCI to fully assess and be able to perform the engineering analyses, we are requesting your assistance by reviewing the accompanying matrix in Attachment I - vehicle list, and supplying as much of the information listed in Attachment II – required data. TTCI will treat the information each manufacturer provides as propriety and will publish results of these analyses anonymously.

TTCI is requesting additional information so that comparisons of advantages and disadvantages of truck design features can be made to determine which truck types are the most suitable for adaptation to the U.S. operating environment. The most promising truck designs will be selected for further analysis. Obsolete or incompatible truck designs that were evaluated in the 1996 study will be removed from consideration and report, and newly introduced truck designs will be added to the list.

TTCI will create vehicle dynamics models for high-speed passenger trucks of the most promising designs. This includes conceptual design studies for emerging technologies such as active dampers for active suspensions and composite materials. Although on-track testing is not proposed under this task order, TTCI will develop a model validation test matrix that defines the testing and measurements required to validate the models. All modeling will be performed by TTCI's engineering staff.

TTCI respectfully requests your cooperation and assistance by reviewing the accompanying matrix, identifying which design(s) you feel would be the most appropriate for this study along with supplying as much of the data as listed in the attached document.

TTCI would like to thank you in advance for your cooperation and assistance and welcome any questions you might have.

Respectfully submitted,

Stan T. Gurulé
Principal
Investigator I

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Information Required for Vehicle Model Preparation

This section details vehicle parameters required to construct a vehicle model. The list is comprehensive and some of the information may not be available. This information is used as a basis for determining what vehicle characterization test should be performed to fully understand the dynamic performance of the vehicle and accurately model it.

Car and Truck Drawings

Manufacturer's drawings are useful in providing vehicle dimensions, weights, details of the assemblies, and attachment details. This information is important in understanding how the vehicle is assembled, locations of suspension systems, and truck assemblies.

Mass, Moment of Inertia and Flexible Modes

The following parameters are required for all components in the system over about 100 pounds:

- Mass
- Mass moments of inertia's for roll, pitch, and yaw
- Center of gravity in x, y, z coordinates

Some components in the system that require parameters specified in a vehicle model are wheelsets, truck frames, and any truck frame subassemblies, traction motors, carbody, and carbody assemblies. Carbodies are usually modeled as lumped masses, although some rail vehicle multibody dynamics codes provide for inclusion of flexible carbody modes. Seats and attached items such as air conditioning units should be included in total mass and inertia.

If the flexible modes are thought to be critical, then torsion, lateral, and vertical bending frequencies of individual car bodies are important for all bodies with bending frequencies less than about 20 Hz.

Car Weights

Total car weights are required for all load conditions of the vehicle. Individual component weights are also required. This information will be input into the vehicle model as mass.

- Total car weight including trucks
- Individual assembled truck weight
- Empty weight
- Maximum loaded weights

Suspension Characteristics

The following characteristics of all major suspension elements, including primary and secondary suspensions, are required for vehicle modeling:

- Force versus displacement graphs (including changes in stiffness)
- Force versus velocity (hydraulics and rubber elements or design parameters for critical damping elements)
- Information of tilting algorithms (if applicable)

- Stiffness of rubber bushings at ends of hydraulic dampers
- Stiffness of rubber bushings used in longitudinal anchor rods and traction links
- Stiffness of traction motor mountings
- Traction motor gear ratios
- Center plate diameter and friction coefficient
- Side bearing spacing and type (including characteristics of spring or elastomeric elements, and friction coefficients)
- Antiroll bars: locations and stiffness values

This should include all bump stops, rotation stops, clearances, and linkages. It is important to understand where the clearance constraints are, their functional directions, and the allowable tolerances at assembly. This information is required for vertical, lateral and longitudinal directions where applicable.

For standard three-piece freight car trucks, the following information will be needed for a vehicle model (the trade name for the truck can identify a source for some of the information):

- Spring group arrangement — number of inners and outers and the pattern for each nest
- Wedge type (constant or variable load; is this modern truck with wider wedges or older truck design)
- Wedge angle
- Wedge rise for each wedge
- Wedge control coil types (inner and outer)

For worn trucks, measurements of significant wear of column wear plates, bolster-side frame gib clearances, and uneven wear patterns are needed to accurately model the vehicle performance.

Airbag Suspensions

The following airbag suspension characteristics are required to accurately model the performance of the system:

- Volumes of air in bags and reservoirs, working pressure, and airbag cross-sectional effective area
- Placement/locations of all valves and sizes
- Orifices locations and sizes of openings
- Piping lengths and inside diameters
- Stiffnesses
    - Vertical
    - Shear (longitudinal, lateral, rotational)
- Detailed schematic of the piping layout and function of the system, e.g., how they are intended to work and function. (Manufacturer data sheets would be extremely helpful.)

- Setup procedures and intended operation
- Operating pressures
- Stiffness of the "emergency" spring and static clearance to the spring — the emergency spring is usually inside the airbag and supports the car if the airbag collapses

Truck Information

It is important to understand the type of truck design that is to be modeled. Suspension characteristics vary among different types of trucks. It is also important to measure the following parameters:

- Wheel back-to-back spacing — lateral distance between the wheels in the wheelset as shown in Figure E1
- Wheel tapeline measurements

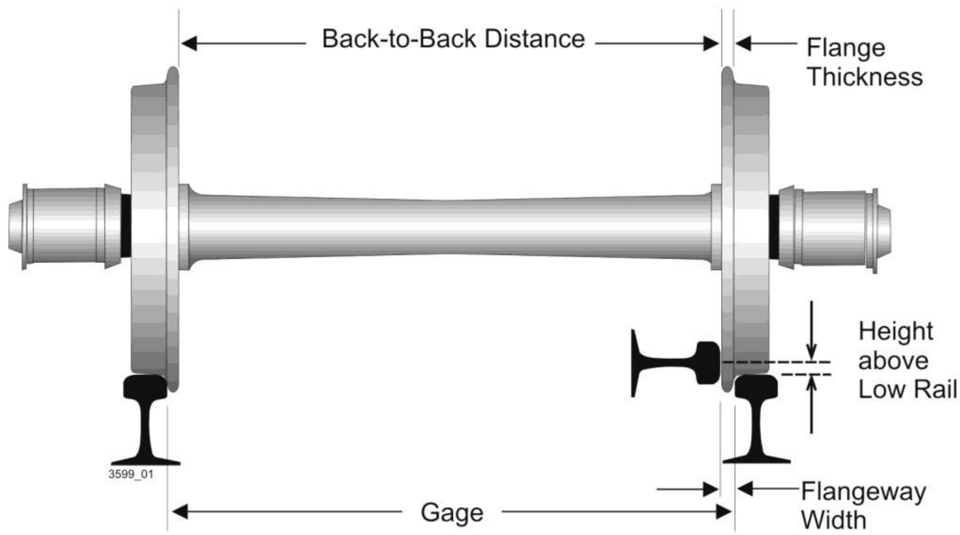

Figure E1. Wheelset Dimensions

Wheel/Rail Profiles and Friction

The shapes of the wheels and rails are required to accurately model the wheel/rail contact geometry. New wheel and rail condition can be taken from drawings. Worn wheel and rail condition must be measured. Figure E2 and Figure E3 show wheel and rail measured with a Greenwood Engineering MiniProfTM Profilometer [2]. Rail profiles may vary substantially on tangent, curve, and spiral track sections. TTCI recommends measuring rail profiles at a number of locations on all types of track.

Lubrication conditions of the track are used to determine coefficients of friction for the mathematical model. Rail limiting friction can be measured with a portable device such as a hand-push tribometer. Wheel-to-rail creepage/force characteristics have a significant influence on vehicle dynamics, particularly for track treated with lubricants and/or friction modifiers. Very few devices exist that can measure creepage/force characteristics on track, so this information is usually not available. Analysts are advised to investigate ranges of creep/force characteristics if their software permits.

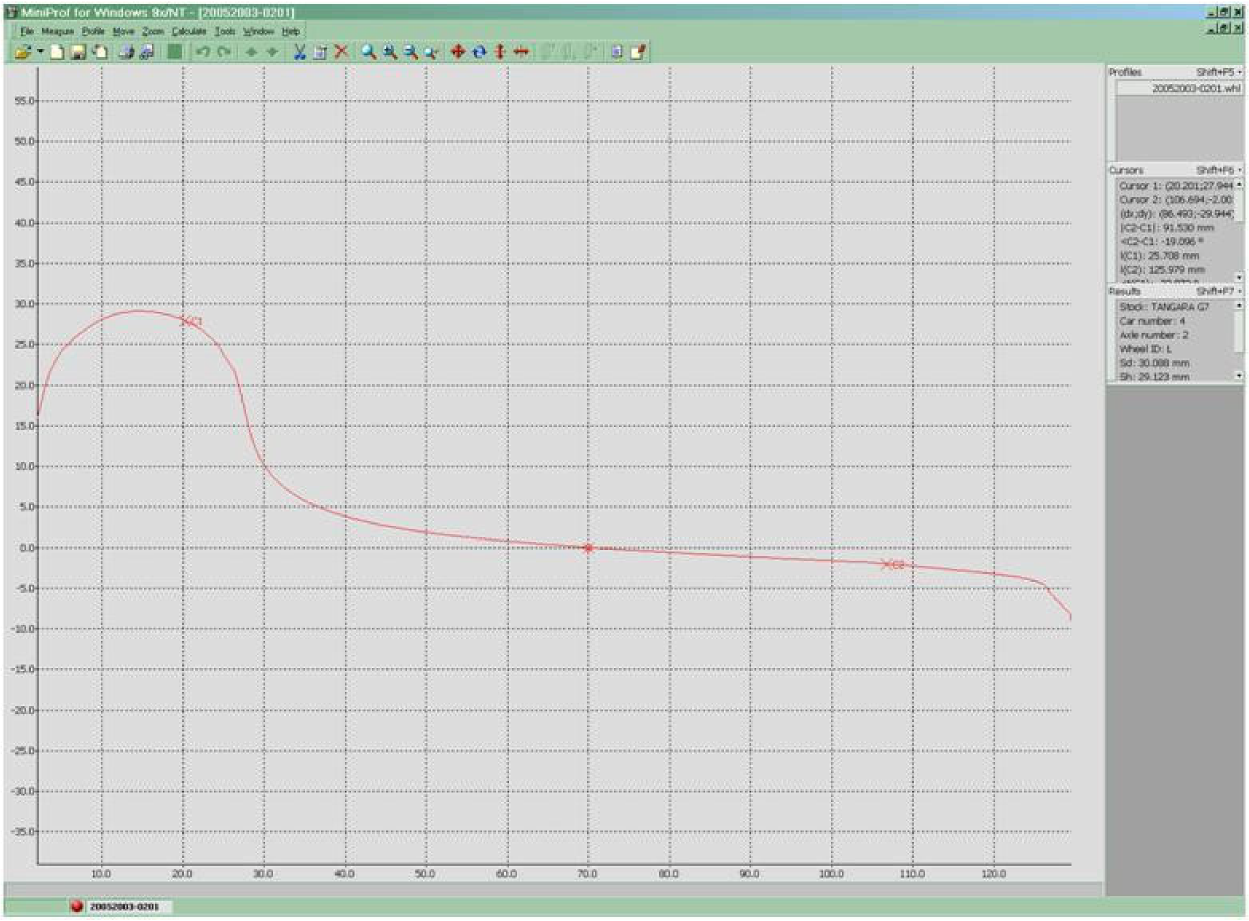

Figure E2. Example of Measured Wheel Profile

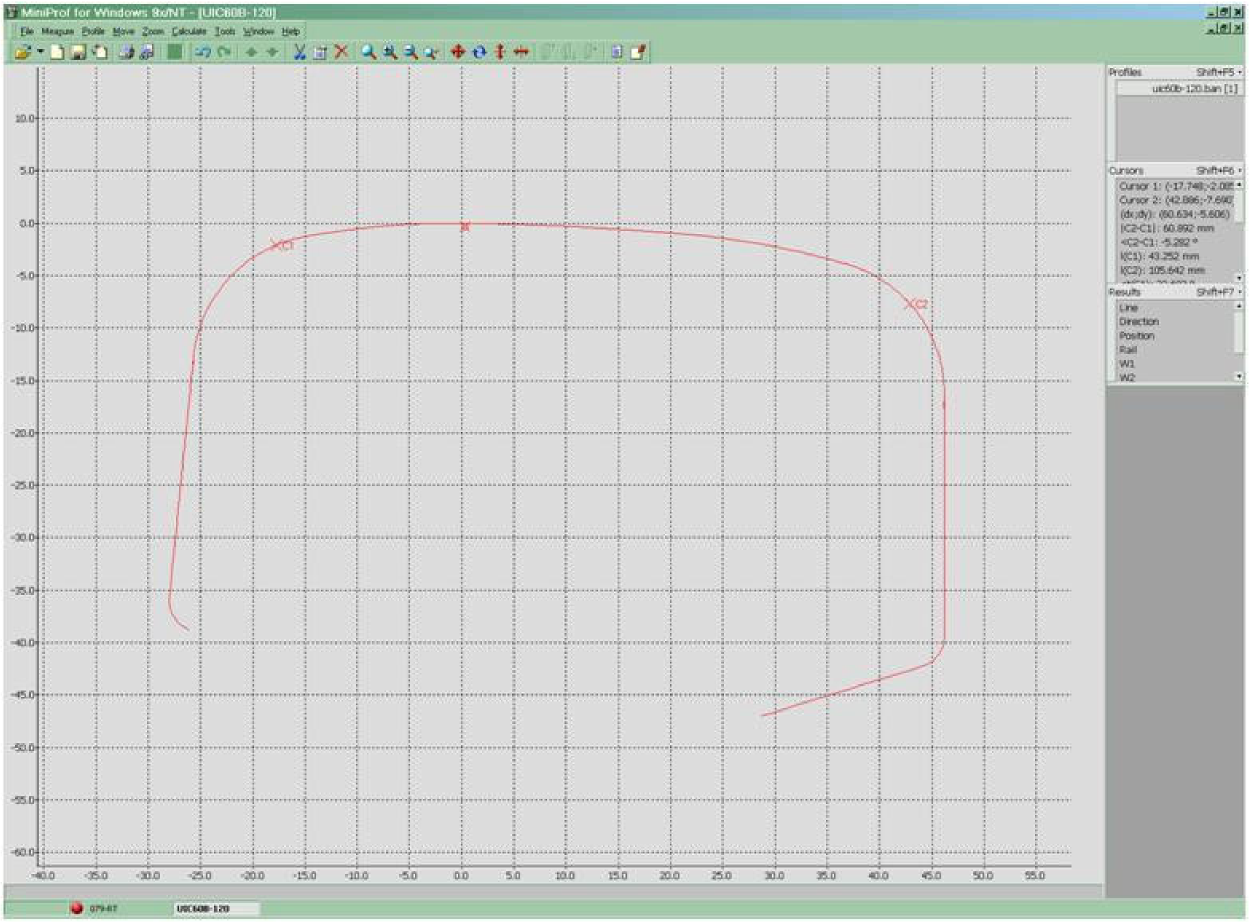

Figure E3. Example of Measured Rail Profile

**Agreement between Transportation Technology Center, Inc.
and Company Name ("the Company")**

for the Anonymous Use of High-Speed Truck Data Relative to FRA Research Project: Design Considerations for High-Speed Trucks on Passenger Vehicles

The Transportation Technology Center, Inc. (TTCI) is currently performing a research project for the Federal Railroad Administration (FRA) – FRA Task Order 325 Design Considerations for High-Speed Trucks on Passenger Vehicles. TTCI has contracted with Parsons Brinckerhoff, Inc. (PBI) to survey the industry and consult with stakeholders to identify, categorize, and analyze the state-of-the-art in high- speed truck technologies. TTCI has prepared a listing of data necessary for vehicle dynamics modeling to be performed by TTCI.

When signed by both parties, this agreement permits TTCI to use data provided by the Company for the sole purpose of performing simulations of vehicle dynamics performance under its contract with FRA (Task Order 325 under FRA Contract DTFR53-11-D-00008) subject to the limitations set forth below.

Specifically, TTCI agrees that TTCI shall only use data provided by the Company in the FRA project as described in the accompanying letter in a manner that preserves and protects the Company's proprietary data and anonymity. TTCI may not publicly identify the data provided by the Company as data related to the Company's truck design, and any published results of the FRA project will be done so anonymously. Data provided by the Company will be treated as proprietary and will not be released in a manner that would identify the Company in relation to the data provided.

TTCI will also grant review authority to the Company pertaining to portions of any reports produced under this agreement that contain the Company's proprietary data. As such, the Company may, in its sole discretion, disapprove the release of any of its proprietary data whose publication it believes to be potentially harmful to the company, even though published anonymously.

______________________________ __________________

David Meeks, VP and CFO | Date

______________________________ __________________

For the Company | Date

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Appendix F.
Chapter 11 Results

Table F1. Curving Results 7.5-degree South Spiral Clockwise Direction

Speed (mph)	Max Roll Angle (deg)	50 ms/3ft Max wheel L/V	6 ft Max truck side L/V	3 ft/50 ms Min vertical wheel load	50 ms/ 3 ft Max axle sum L/V	Max 95% Wheel L/V	Max 95% axle sum L/V	Max Angle of Attack (mrad)
Criterion								
	< 6	< 1.0	< 0.6	> 10%	< 1.5	< 0.8	< 1.5	N/A
Equalizer Beam, SL								
12	0.5	0.66	0.31	68.4%	1.13	0.57	1.05	12.58
24	0.5	0.63	0.30	65.0%	1.08	0.57	1.05	12.06
32	1.0	0.60	0.28	62.2%	1.08	0.59	1.06	11.75
Equalizer Beam, BL								
12	0.8	0.64	0.29	70.5%	1.13	0.59	1.08	12.47
24	1.5	0.57	0.27	74.1%	1.05	0.55	1.03	12.09
32	1.4	0.56	0.28	61.3%	1.01	0.54	1.01	11.72
Radial Arm, SL								
12	0.5	0.66	0.30	67.7%	1.16	0.58	1.06	12.31
24	0.5	0.63	0.28	64.0%	1.11	0.59	1.06	11.71
32	1.1	0.62	0.26	58.6%	1.10	0.60	1.07	11.26
Radial Arm, BL								
12	1.8	0.79	0.31	59.0%	1.28	0.65	1.13	12.25
24	1.6	0.68	0.30	65.4%	1.17	0.59	1.07	11.61
32	1.1	0.58	0.25	63.1%	1.05	0.54	1.01	10.97
Radial Chevron, SL								
12	0.5	0.60	0.29	64.2%	1.08	0.56	1.03	10.26
24	0.8	0.68	0.27	54.0%	1.16	0.55	1.02	9.80
32	1.5	0.59	0.29	61.6%	1.07	0.56	1.01	9.55
Radial Chevron, BL								
12	1.7	0.77	0.29	60.0%	1.25	0.62	1.08	9.28
24	1.8	0.65	0.27	62.5%	1.12	0.53	0.97	8.92
32	1.2	0.51	0.25	61.7%	0.96	0.48	0.92	8.72
Conical Spring, SL								
12	0.6	0.58	0.28	64.7%	1.07	0.51	0.98	8.74

Speed (mph)	Max Roll Angle (deg)	50 ms/3ft Max wheel L/V	6 ft Max truck side L/V	3 ft/50 ms Min vertical wheel load	50 ms/ 3 ft Max axle sum L/V	Max 95% Wheel L/V	Max 95% axle sum L/V	Max Angle of Attack (mrad)
24	0.7	0.56	0.26	62.5%	1.03	0.51	0.97	8.39
32	1.6	0.54	0.27	54.3%	1.01	0.49	0.95	8.31
				Conical Spring, BL				
12	1.5	0.67	0.26	60.2%	1.16	0.50	0.97	7.44
24	2.0	0.56	0.25	65.9%	1.03	0.46	0.91	7.25
32	1.6	0.46	0.25	65.9%	0.91	0.45	0.85	7.14
				Journal Spring, SL				
12	0.6	0.66	0.30	72.2%	1.15	0.58	1.06	11.36
24	0.8	0.64	0.27	68.5%	1.12	0.58	1.06	10.94
32	1.6	0.56	0.26	66.9%	1.05	0.59	1.05	10.57
				Journal Spring, BL				
12	0.8	0.71	0.29	73.3%	1.20	0.63	1.11	11.40
24	1.6	0.65	0.29	69.5%	1.12	0.59	1.06	11.01
32	0.7	0.55	0.25	71.0%	1.03	0.53	1.00	10.57

Table F2. Curving Results 7.5-degree North Spiral Clockwise Direction

Speed (mph)	Max Roll Angle (deg)	50 ms/3ft Max wheel L/V	6 ft Max truck side L/V	3 ft/50 ms Min vertical wheel load	50 ms/ 3 ft Max axle sum L/V	Max 95% Wheel L/V	Max 95% axle sum L/V	Max Angle of Attack (mrad)
				Criterion				
	< 6	**< 1.0**	**< 0.6**	**> 10%**	**< 1.5**	**< 0.8**	**< 1.5**	**N/A**
				Equalizer Beam, SL				
12	0.4	0.61	0.29	77.0%	1.09	0.56	1.04	12.39
24	0.6	0.58	0.26	76.0%	1.06	0.55	1.02	12.10
32	0.7	0.54	0.27	64.7%	1.01	0.55	1.02	11.75
				Equalizer Beam, BL				
12	0.5	0.63	0.29	79.5%	1.11	0.56	1.04	12.25
24	1.1	0.60	0.28	70.7%	1.07	0.53	1.00	11.98
32	1.1	0.54	0.26	64.1%	1.01	0.52	0.99	11.63
				Radial Arm, SL				
12	0.5	0.62	0.30	75.0%	1.11	0.57	1.05	12.59
24	0.8	0.61	0.29	72.9%	1.10	0.56	1.04	12.21
32	1.1	0.60	0.27	62.6%	1.08	0.57	1.04	11.86
				Radial Arm, BL				
12	1.2	0.66	0.30	75.2%	1.15	0.58	1.06	12.45
24	2.1	0.65	0.30	65.9%	1.12	0.57	1.04	12.07
32	1.4	0.59	0.28	58.8%	1.04	0.55	1.01	11.60
				Rubber Chevron, SL				
12	0.5	0.61	0.28	73.8%	1.08	0.54	1.00	10.62
24	0.9	0.65	0.27	67.9%	1.12	0.55	1.00	10.16
32	1.6	0.62	0.28	57.7%	1.08	0.53	0.97	10.01

Speed (mph)	Max Roll Angle (deg)	50 ms/3ft Max wheel L/V	6 ft Max truck side L/V	3 ft/50 ms Min vertical wheel load	50 ms/ 3 ft Max axle sum L/V	Max 95% Wheel L/V	Max 95% axle sum L/V	Max Angle of Attack (mrad)
				Rubber Chevron, BL				
12	1.4	0.64	0.27	75.5%	1.11	0.53	0.98	9.51
24	1.9	0.56	0.27	70.3%	1.03	0.50	0.95	9.24
32	1.0	0.52	0.25	66.8%	0.96	0.47	0.91	9.17
				Conical Spring, SL				
12	0.4	0.57	0.27	76.7%	1.05	0.53	0.99	9.13
24	0.9	0.56	0.27	70.8%	1.03	0.51	0.98	9.04
32	1.1	0.56	0.28	59.5%	1.00	0.50	0.96	8.85
				Conical Spring, BL				
12	1.6	0.57	0.26	76.3%	1.05	0.49	0.95	7.68
24	1.6	0.57	0.27	73.3%	1.03	0.47	0.93	7.52
32	1.2	0.51	0.25	61.4%	0.93	0.45	0.85	7.42
				Journal Spring, SL				
12	0.5	0.63	0.29	77.3%	1.12	0.56	1.04	11.55
24	1.0	0.61	0.29	75.6%	1.08	0.56	1.03	11.28
32	1.2	0.59	0.28	68.8%	1.05	0.56	1.03	10.82
				Journal Spring, BL				
12	1.0	0.67	0.29	72.3%	1.15	0.60	1.07	11.62
24	1.0	0.63	0.29	75.9%	1.10	0.56	1.04	11.32
32	0.7	0.57	0.28	70.8%	1.00	0.52	0.98	10.86

Table F3. Curving Results 7.5-degree Curve Clockwise Direction

Speed (mph)	Max Roll Angle (deg)	50 ms/3ft Max wheel L/V	6 ft Max truck side L/V	3 ft/50 ms Min vertical wheel load	50 ms/ 3 ft Max axle sum L/V	Max 95% Wheel L/V	Max 95% axle sum L/V	Max Angle of Attack (mrad)
				Criterion				
	< 6	< 1.0	< 0.6	> 10%	< 1.5	< 0.8	< 1.5	N/A
				Equalizer Beam, SL				
12	0.4	0.66	0.32	77.2%	1.15	0.59	1.07	15.60
24	0.5	0.63	0.29	79.3%	1.13	0.59	1.07	15.41
32	0.8	0.61	0.29	69.6%	1.10	0.63	1.10	15.19
				Equalizer Beam, BL				
12	0.5	0.69	0.32	73.2%	1.19	0.60	1.09	15.64
24	0.9	0.64	0.28	75.4%	1.14	0.57	1.05	15.42
32	1.3	0.64	0.29	64.8%	1.14	0.58	1.05	15.19
				Radial Arm, SL				
12	0.5	0.68	0.33	76.7%	1.18	0.59	1.08	14.49
24	0.6	0.62	0.30	78.7%	1.12	0.61	1.09	14.00
32	1.1	0.61	0.30	63.2%	1.09	0.62	1.10	13.66
				Radial Arm, BL				
12	0.8	0.71	0.33	69.3%	1.20	0.63	1.11	14.07
24	1.3	0.62	0.28	73.5%	1.11	0.59	1.07	13.66
32	1.7	0.64	0.30	58.1%	1.13	0.57	1.04	13.05
				Rubber Chevron, SL				
12	0.5	0.67	0.31	75.4%	1.17	0.58	1.05	12.81
24	1.0	0.73	0.29	70.4%	1.22	0.61	1.08	12.59
32	2.0	0.71	0.33	55.8%	1.20	0.60	1.07	12.21
				Rubber Chevron, BL				

Speed (mph)	Max Roll Angle (deg)	50 ms/3ft Max wheel L/V	6 ft Max truck side L/V	3 ft/50 ms Min vertical wheel load	50 ms/ 3 ft Max axle sum L/V	Max 95% Wheel L/V	Max 95% axle sum L/V	Max Angle of Attack (mrad)
12	1.2	0.71	0.30	69.0%	1.21	0.60	1.07	11.55
24	1.4	0.67	0.27	75.8%	1.15	0.53	0.99	11.31
32	1.8	0.67	0.30	59.3%	1.14	0.50	0.96	11.06
Conical Spring, SL								
12	0.5	0.64	0.31	77.5%	1.14	0.54	1.02	11.85
24	0.7	0.61	0.27	78.8%	1.10	0.54	1.01	11.74
32	1.1	0.58	0.30	56.0%	1.08	0.54	1.00	11.59
Conical Spring, BL								
12	1.1	0.65	0.30	70.9%	1.16	0.54	1.01	10.40
24	1.4	0.55	0.26	75.9%	1.05	0.49	0.95	10.32
32	1.7	0.57	0.28	59.1%	1.05	0.47	0.92	10.19
Journal Spring, SL								
12	0.5	0.69	0.33	76.3%	1.18	0.60	1.08	13.66
24	0.9	0.65	0.30	76.3%	1.15	0.60	1.08	13.56
32	1.1	0.61	0.29	67.8%	1.10	0.61	1.09	13.28
Journal Spring, BL								
12	0.7	0.70	0.33	71.5%	1.21	0.64	1.12	13.27
24	2.2	0.71	0.32	73.5%	1.21	0.62	1.10	13.15
32	0.6	0.59	0.28	68.7%	1.09	0.54	1.01	12.69

Table F4. Curving Results 10-degree South Spiral Clockwise Direction

Speed (mph)	Max Roll Angle (deg)	50 ms/3ft Max wheel L/V	6 ft Max truck side L/V	3 ft/50 ms Min vertical wheel load	50 ms/ 3 ft Max axle sum L/V	Max 95% Wheel L/V	Max 95% axle sum L/V	Max Angle of Attack (mrad)
Criterion								
	< 6	**< 1.0**	**< 0.6**	**> 10%**	**< 1.5**	**< 0.8**	**< 1.5**	**N/A**
Equalizer Beam, SL								
12	0.4	0.68	0.34	68.7 %	1.15	0.63	1.11	18.81
24	0.4	0.64	0.33	61.2 %	1.14	0.62	1.10	18.39
32	0.7	0.65	0.34	56.8 %	1.15	0.64	1.11	17.96
Equalizer Beam, BL								
12	0.9	0.68	0.33	71.7 %	1.18	0.64	1.14	18.46
24	0.8	0.65	0.30	65.8 %	1.15	0.61	1.10	18.17
32	1.1	0.62	0.30	57.1 %	1.12	0.59	1.08	17.90
Radial Arm, SL								
12	0.5	0.65	0.36	65.1 %	1.16	0.59	1.08	18.64
24	0.6	0.67	0.31	57.5 %	1.17	0.60	1.10	18.16
32	0.9	0.65	0.32	50.5 %	1.14	0.62	1.10	17.41
Radial Arm, BL								
12	1.4	0.72	0.35	70.1 %	1.22	0.66	1.16	18.28
24	2.0	0.73	0.36	59.6 %	1.23	0.64	1.13	17.49
32	1.0	0.61	0.31	54.4	1.10	0.58	1.07	17.07

Speed (mph)	Max Roll Angle (deg)	50 ms/3ft Max wheel L/V	6 ft Max truck side L/V	3 ft/50 ms Min vertical wheel load %	50 ms/ 3 ft Max axle sum L/V	Max 95% Wheel L/V	Max 95% axle sum L/V	Max Angle of Attack (mrad)
				Rubber Chevron, SL				
12	0.5	0.65	0.34	64.0 %	1.14	0.59	1.08	16.60
24	0.9	0.73	0.31	54.1 %	1.23	0.61	1.09	16.23
32	1.8	0.78	0.38	28.1 %	1.27	0.65	1.12	16.01
				Rubber Chevron, BL				
12	1.6	0.73	0.33	69.2 %	1.22	0.65	1.14	15.21
24	1.7	0.75	0.35	61.5 %	1.24	0.64	1.11	14.66
32	1.4	0.61	0.29	58.4 %	1.08	0.54	1.02	14.24
				Conical Spring, SL				
12	0.5	0.65	0.33	67.8 %	1.15	0.58	1.07	15.27
24	0.7	0.64	0.32	55.2 %	1.15	0.58	1.07	15.08
32	1.1	0.61	0.32	43.3 %	1.10	0.58	1.06	15.14
				Conical Spring, BL				
12	1.9	0.72	0.33	62.8 %	1.23	0.62	1.10	14.04
24	1.6	0.68	0.33	65.8 %	1.17	0.58	1.06	14.11
32	1.5	0.53	0.29	41.4 %	1.01	0.49	0.98	14.18
				Journal Spring, SL				
12	0.5	0.67	0.36	71.5 %	1.18	0.60	1.10	17.49
24	0.8	0.69	0.33	59.6 %	1.19	0.61	1.10	17.34
32	0.8	0.65	0.31	57.0 %	1.15	0.62	1.10	16.63
				Journal Spring, BL				
12	1.1	0.76	0.36	68.4 %	1.26	0.69	1.18	17.31
24	1.2	0.69	0.34	68.4 %	1.18	0.64	1.13	17.21
32	0.6	0.58	0.28	60.8 %	1.07	0.56	1.04	16.49

Table F5. Curving Results 10-degree North Spiral Clockwise Direction

Speed (mph)	Max Roll Angle (deg)	50 ms/3ft Max wheel L/V	6 ft Max truck side L/V	3 ft/50 ms Min vertical wheel load	50 ms/ 3 ft Max axle sum L/V	Max 95% Wheel L/V	Max 95% axle sum L/V	Max Angle of Attack (mrad)
				Criterion				
	< 6	**< 1.0**	**< 0.6**	**> 10%**	**< 1.5**	**< 0.8**	**< 1.5**	**N/A**
				Equalizer Beam, SL				
12	0.3	0.65	0.33	78.6 %	1.15	0.59	1.09	18.24

Speed (mph)	Max Roll Angle (deg)	50 ms/3ft Max wheel L/V	6 ft Max truck side L/V	3 ft/50 ms Min vertical wheel load	50 ms/ 3 ft Max axle sum L/V	Max 95% Wheel L/V	Max 95% axle sum L/V	Max Angle of Attack (mrad)
24	0.3	0.62	0.29	77.2 %	1.12	0.60	1.09	17.89
32	0.8	0.60	0.29	63.6 %	1.08	0.61	1.09	17.33
				Equalizer Beam, BL				
12	0.6	0.70	0.32	75.5 %	1.19	0.62	1.12	18.01
24	1.3	0.65	0.29	70.9 %	1.14	0.59	1.08	17.88
32	0.7	0.58	0.28	64.5 %	1.06	0.55	1.03	17.16
				Radial Arm, SL				
12	0.4	0.63	0.35	76.9 %	1.13	0.59	1.08	18.19
24	0.5	0.61	0.31	76.1 %	1.10	0.60	1.09	17.71
32	1.1	0.61	0.29	56.5 %	1.09	0.61	1.09	17.23
				Radial Arm, BL				
12	1.4	0.72	0.36	68.3 %	1.22	0.64	1.14	17.89
24	1.0	0.62	0.30	74.7 %	1.11	0.58	1.07	17.33
32	1.2	0.58	0.28	57.1 %	1.06	0.56	1.04	16.70
				Rubber Chevron, SL				
12	0.5	0.66	0.33	72.3 %	1.15	0.58	1.06	16.28
24	1.0	0.68	0.30	69.5 %	1.16	0.59	1.07	15.76
32	1.2	0.65	0.32	60.5 %	1.12	0.59	1.06	15.10
				Rubber Chevron, BL				
12	1.4	0.74	0.31	71.3 %	1.22	0.64	1.12	15.11
24	1.2	0.65	0.31	72.2 %	1.12	0.56	1.04	14.25
32	1.6	0.57	0.30	52.3 %	1.04	0.54	1.01	14.03
				Conical Spring, SL				
12	0.4	0.64	0.32	76.9 %	1.14	0.58	1.07	14.41
24	0.5	0.61	0.29	75.5 %	1.11	0.57	1.05	14.11
32	1.3	0.63	0.31	49.7 %	1.11	0.56	1.03	14.16
				Conical Spring, BL				
12	1.4	0.67	0.32	71.8 %	1.16	0.59	1.07	13.24
24	1.1	0.56	0.28	76.7 %	1.05	0.51	0.99	12.90
32	1.5	0.55	0.30	57.2 %	1.03	0.48	0.95	13.45
				Journal Spring, SL				
12	0.4	0.64	0.35	77.1 %	1.14	0.60	1.09	17.17
24	0.5	0.62	0.31	77.5	1.10	0.60	1.09	16.96

Speed (mph)	Max Roll Angle (deg)	50 ms/3ft Max wheel L/V	6 ft Max truck side L/V	3 ft/50 ms Min vertical wheel load	50 ms/ 3 ft Max axle sum L/V	Max 95% Wheel L/V	Max 95% axle sum L/V	Max Angle of Attack (mrad)
				%				
32	1.0	0.60	0.29	60.3 %	1.09	0.60	1.08	16.69
				Journal Spring, BL				
12	0.8	0.72	0.35	72.2 %	1.21	0.66	1.16	16.93
24	1.3	0.63	0.31	76.1 %	1.13	0.61	1.10	16.84
32	0.7	0.56	0.27	60.6 %	1.04	0.55	1.03	16.14

Table F6. Curving Results 10-degree Curve Clockwise Direction

Speed (mph)	Max Roll Angle (deg)	50 ms/3ft Max wheel L/V	6 ft Max truck side L/V	3 ft/50 ms Min vertical wheel load	50 ms/ 3 ft Max axle sum L/V	Max 95% Wheel L/V	Max 95% axle sum L/V	Max Angle of Attack (mrad)
				Criterion				
	< 6	**< 1.0**	**< 0.6**	**> 10%**	**< 1.5**	**< 0.8**	**< 1.5**	**N/A**
				Equalizer Beam, SL				
12	0.3	0.68	0.34	76.8 %	1.18	0.62	1.12	19.09
24	0.5	0.68	0.31	77.9 %	1.17	0.63	1.12	18.57
32	0.8	0.65	0.31	63.0 %	1.15	0.67	1.16	18.27
				Equalizer Beam, BL				
12	0.4	0.70	0.33	74.7 %	1.19	0.66	1.16	18.74
24	1.3	0.73	0.34	70.9 %	1.23	0.64	1.13	18.04
32	1.1	0.64	0.30	56.3 %	1.14	0.62	1.10	17.73
				Radial Arm, SL				
12	0.4	0.68	0.35	73.0 %	1.18	0.61	1.11	19.29
24	0.6	0.67	0.32	75.0 %	1.17	0.63	1.12	18.87
32	1.1	0.66	0.33	56.5 %	1.15	0.66	1.15	18.47
				Radial Arm, BL				
12	1.1	0.72	0.35	67.6 %	1.22	0.67	1.17	19.02
24	1.9	0.72	0.36	65.6 %	1.22	0.65	1.14	18.20
32	1.2	0.61	0.30	54.2 %	1.10	0.59	1.08	17.67
				Rubber Chevron, SL				
12	0.5	0.69	0.34	75.6 %	1.18	0.61	1.10	17.25
24	0.8	0.79	0.31	69.5 %	1.27	0.64	1.13	17.02
32	1.4	0.76	0.38	53.2 %	1.24	0.65	1.13	16.86
				Rubber Chevron, BL				

Speed (mph)	Max Roll Angle (deg)	50 ms/3ft Max wheel L/V	6 ft Max truck side L/V	3 ft/50 ms Min vertical wheel load	50 ms/ 3 ft Max axle sum L/V	Max 95% Wheel L/V	Max 95% axle sum L/V	Max Angle of Attack (mrad)
12	1.1	0.74	0.32	68.9 %	1.22	0.67	1.15	15.69
24	1.6	0.72	0.33	69.2 %	1.21	0.62	1.10	14.91
32	1.3	0.60	0.29	52.3 %	1.06	0.55	1.02	14.86
				Conical Spring, SL				
12	0.4	0.67	0.34	75.6 %	1.17	0.61	1.11	15.59
24	0.8	0.65	0.32	73.0 %	1.15	0.60	1.09	15.72
32	1.3	0.68	0.33	49.7 %	1.17	0.61	1.09	15.51
				Conical Spring, BL				
12	1.1	0.70	0.33	71.4 %	1.21	0.64	1.13	14.70
24	1.6	0.65	0.31	68.9 %	1.14	0.59	1.07	14.49
32	1.3	0.55	0.31	57.2 %	1.05	0.52	1.01	14.84
				Journal Spring, SL				
12	0.4	0.69	0.35	75.8 %	1.19	0.63	1.12	18.25
24	0.9	0.69	0.33	75.0 %	1.19	0.63	1.12	18.04
32	1.2	0.67	0.32	59.5 %	1.16	0.65	1.13	17.24
				Journal Spring, BL				
12	0.9	0.75	0.35	70.0 %	1.25	0.69	1.19	18.01
24	1.7	0.71	0.35	71.8 %	1.20	0.66	1.15	17.60
32	0.5	0.59	0.28	60.2 %	1.07	0.57	1.05	17.11

Table F7. Curving Results 12-degree South Spiral Clockwise Direction

Speed (mph)	Max Roll Angle (deg)	50 ms/3ft Max wheel L/V	6 ft Max truck side L/V	3 ft/50 ms Min vertical wheel load	50 ms/ 3 ft Max axle sum L/V	Max 95% Wheel L/V	Max 95% axle sum L/V	Max Angle of Attack (mrad)
				Criterion				
	< 6	**< 1.0**	**< 0.6**	**> 10%**	**< 1.5**	**< 0.8**	**< 1.5**	**N/A**
				Equalizer Beam, SL				
12	0.3	0.73	0.35	67.8%	1.23	0.65	1.14	21.20
24	0.4	0.70	0.35	65.7%	1.19	0.65	1.14	20.94
32	0.4	0.66	0.33	58.0%	1.15	0.67	1.15	20.23
				Equalizer Beam, BL				
12	0.4	0.73	0.34	68.3%	1.22	0.67	1.17	21.19
24	0.5	0.66	0.32	70.7%	1.15	0.63	1.13	20.86
32	0.8	0.58	0.30	59.0%	1.07	0.59	1.08	20.37
				Radial Arm, SL				
12	0.3	0.63	0.37	65.9%	1.13	0.59	1.09	20.73
24	0.4	0.64	0.33	63.9%	1.14	0.61	1.11	20.13
32	0.6	0.61	0.32	54.3%	1.11	0.64	1.13	19.24
				Radial Arm, BL				

Speed (mph)	Max Roll Angle (deg)	50 ms/3ft Max wheel L/V	6 ft Max truck side L/V	3 ft/50 ms Min vertical wheel load	50 ms/ 3 ft Max axle sum L/V	Max 95% Wheel L/V	Max 95% axle sum L/V	Max Angle of Attack (mrad)
12	0.8	0.72	0.38	66.0%	1.22	0.67	1.17	20.83
24	1.7	0.70	0.36	61.3%	1.20	0.64	1.14	20.09
32	1.0	0.60	0.29	58.6%	1.09	0.59	1.08	18.80
				Rubber Chevron, SL				
12	0.4	0.65	0.36	65.6%	1.15	0.61	1.10	19.07
24	0.7	0.68	0.32	59.9%	1.17	0.62	1.11	18.48
32	1.2	0.71	0.34	43.6%	1.20	0.63	1.11	17.77
				Rubber Chevron, BL				
12	1.3	0.74	0.36	65.8%	1.24	0.70	1.19	18.13
24	1.7	0.74	0.36	62.9%	1.23	0.67	1.16	17.22
32	0.8	0.60	0.29	60.1%	1.09	0.57	1.05	16.55
				Conical Spring, SL				
12	0.4	0.64	0.35	64.7%	1.14	0.60	1.10	17.03
24	0.6	0.64	0.32	61.4%	1.14	0.61	1.10	16.57
32	0.8	0.61	0.31	47.2%	1.10	0.59	1.08	16.50
				Conical Spring, BL				
12	1.5	0.67	0.33	63.4%	1.17	0.65	1.15	16.03
24	1.5	0.67	0.34	66.4%	1.16	0.62	1.11	15.71
32	0.9	0.56	0.31	55.6%	1.05	0.52	1.01	15.39
				Journal Spring, SL				
12	0.4	0.65	0.37	70.3%	1.16	0.62	1.12	19.87
24	0.7	0.67	0.34	66.3%	1.17	0.62	1.12	19.51
32	0.7	0.62	0.33	57.1%	1.11	0.63	1.12	18.70
				Journal Spring, BL				
12	0.5	0.75	0.40	65.7%	1.26	0.71	1.21	19.94
24	1.0	0.65	0.33	71.3%	1.15	0.64	1.14	19.57
32	0.6	0.57	0.29	62.1%	1.06	0.57	1.06	18.69

Table F8. Curving Results 12-degree Bunched Spiral Clockwise Direction

Speed (mph)	Max Roll Angle (deg)	50 ms/3ft Max wheel L/V	6 ft Max truck side L/V	3 ft/50 ms Min vertical wheel load	50 ms/ 3 ft Max axle sum L/V	Max 95% Wheel L/V	Max 95% axle sum L/V	Max Angle of Attack (mrad)
				Criterion				
	< 6	**< 1.0**	**< 0.6**	**> 10%**	**< 1.5**	**< 0.8**	**< 1.5**	**N/A**
				Equalizer Beam, SL				
12	0.7	0.88	0.46	54.5 %	1.35	0.76	1.23	20.41
24	0.9	0.84	0.45	58.3 %	1.30	0.73	1.20	20.06
32	1.0	0.81	0.44	48.6 %	1.28	0.71	1.17	19.67
				Equalizer Beam, BL				
12	0.8	0.77	0.39	62.1 %	1.24	0.69	1.18	20.08
24	1.1	0.73	0.39	67.7 %	1.19	0.65	1.14	19.82
32	1.5	0.63	0.33	48.6 %	1.12	0.60	1.10	19.19
				Radial Arm, SL				
12	0.7	0.89	0.43	60.3 %	1.36	0.76	1.24	19.89

Speed (mph)	Max Roll Angle (deg)	50 ms/3ft Max wheel L/V	6 ft Max truck side L/V	3 ft/50 ms Min vertical wheel load	50 ms/ 3 ft Max axle sum L/V	Max 95% Wheel L/V	Max 95% axle sum L/V	Max Angle of Attack (mrad)
24	0.9	0.82	0.41	62.7 %	1.29	0.73	1.21	19.36
32	1.0	0.75	0.40	52.5 %	1.22	0.69	1.16	18.73
				Radial Beam, BL				
12	0.8	0.77	0.37	63.0 %	1.24	0.72	1.19	19.80
24	1.2	0.68	0.34	67.4 %	1.17	0.64	1.13	19.16
32	1.7	0.61	0.31	56.4 %	1.09	0.59	1.08	18.07
				Rubber Chevron, SL				
12	0.7	0.90	0.42	53.2 %	1.36	0.75	1.21	18.09
24	1.2	0.84	0.41	54.5 %	1.27	0.70	1.16	17.54
32	1.5	0.83	0.43	51.8 %	1.26	0.65	1.12	16.91
				Rubber Chevron, BL				
12	1.0	0.74	0.36	58.3 %	1.23	0.70	1.19	17.06
24	1.3	0.71	0.33	67.1 %	1.20	0.67	1.15	16.16
32	2.2	0.63	0.30	55.3 %	1.10	0.58	1.05	15.50
				Conical Spring, SL				
12	0.8	0.89	0.42	55.3 %	1.33	0.74	1.20	15.85
24	0.9	0.82	0.40	59.3 %	1.25	0.68	1.15	15.24
32	1.0	0.78	0.38	56.2 %	1.19	0.66	1.11	14.72
				Conical Spring, BL				
12	1.0	0.71	0.33	59.9 %	1.21	0.64	1.14	14.46
24	1.4	0.64	0.31	67.5 %	1.14	0.58	1.07	13.85
32	2.2	0.55	0.28	58.5 %	1.04	0.51	0.99	13.97
				Journal Spring, SL				
12	0.8	0.78	0.37	64.7 %	1.24	0.67	1.15	18.92
24	0.9	0.70	0.36	67.6 %	1.16	0.64	1.12	18.62
32	1.2	0.65	0.36	57.5 %	1.11	0.63	1.12	17.90
				Journal Spring, BL				
12	1.9	0.82	0.43	56.4 %	1.32	0.73	1.23	18.78
24	2.5	0.74	0.38	66.8 %	1.23	0.68	1.17	18.57
32	1.2	0.60	0.30	63.7 %	1.09	0.59	1.08	17.85

Table F9. Curving Results 12-degree Curve Clockwise Direction

Speed (mph)	Max Roll Angle (deg)	50 ms/3ft Max wheel L/V	6 ft Max truck side L/V	3 ft/50 ms Min vertical wheel load	50 ms/ 3 ft Max axle sum L/V	Max 95% Wheel L/V	Max 95% axle sum L/V	Max Angle of Attack (mrad)
Criterion								
	< 6	**< 1.0**	**< 0.6**	**> 10%**	**< 1.5**	**< 0.8**	**< 1.5**	**N/A**
Equalizer Beam, SL								
12	0.3	0.65	0.35	75.6%	1.15	0.63	1.13	22.28
24	0.4	0.63	0.32	80.9%	1.13	0.66	1.15	21.97
32	0.8	0.66	0.33	63.6%	1.15	0.70	1.19	21.54
Equalizer Beam, BL								
12	0.5	0.70	0.34	70.9%	1.21	0.68	1.19	22.04
24	1.0	0.67	0.32	77.5%	1.17	0.67	1.16	21.91
32	0.9	0.60	0.29	63.1%	1.09	0.65	1.14	21.07
Radial Arm, SL								
12	0.4	0.69	0.37	72.4%	1.20	0.62	1.12	22.51
24	0.5	0.62	0.32	73.8%	1.12	0.64	1.14	21.94
32	1.0	0.65	0.33	59.3%	1.15	0.66	1.16	21.39
Radial Arm, BL								
12	0.6	0.73	0.36	65.3%	1.24	0.69	1.20	21.97
24	0.6	0.67	0.32	81.8%	1.18	0.64	1.13	21.42
32	0.8	0.61	0.29	61.1%	1.10	0.60	1.10	20.46
Rubber Chevron, SL								
12	0.5	0.73	0.36	73.0%	1.23	0.64	1.13	20.22
24	0.6	0.74	0.33	71.5%	1.24	0.65	1.14	19.50
32	1.3	0.66	0.33	57.3%	1.15	0.64	1.12	19.07
Rubber Chevron, BL								
12	0.6	0.75	0.36	65.3%	1.25	0.71	1.20	18.62
24	1.1	0.71	0.32	78.2%	1.21	0.66	1.15	18.16
32	0.8	0.60	0.28	61.8%	1.08	0.58	1.07	17.54
Conical Spring, BL								
12	0.6	0.70	0.35	72.6%	1.21	0.62	1.11	18.65
24	0.6	0.67	0.32	73.7%	1.17	0.62	1.12	18.09
32	1.1	0.69	0.34	59.1%	1.19	0.65	1.14	17.66
Conical Spring, BL								
12	0.6	0.70	0.33	71.5%	1.21	0.66	1.16	16.73
24	1.1	0.69	0.32	78.9%	1.20	0.62	1.12	16.54
32	0.7	0.55	0.29	61.7%	1.05	0.54	1.03	16.16
Journal Spring, SL								
12	0.6	0.71	0.37	73.5%	1.22	0.64	1.15	21.31
24	0.8	0.63	0.33	77.7%	1.15	0.64	1.14	21.04
32	0.9	0.62	0.31	63.5%	1.11	0.66	1.15	20.53
Journal Spring, BL								
12	1.5	0.76	0.37	65.7%	1.27	0.71	1.22	21.01
24	1.1	0.68	0.34	78.2%	1.18	0.66	1.16	20.66
32	0.4	0.56	0.27	62.1%	1.06	0.58	1.07	19.95

Table F10. Curving Results 7.5-degree South Spiral Counter-Clockwise Direction

Speed (mph)	Max Roll Angle (deg)	50 ms/3ft Max wheel L/V	6 ft Max truck side L/V	3 ft/50 ms Min vertical wheel load	50 ms/ 3 ft Max axle sum L/V	Max 95% Wheel L/V	Max 95% axle sum L/V	Max Angle of Attack (mrad)
				Criterion				
	< 6	**< 1.0**	**< 0.6**	**> 10%**	**< 1.5**	**< 0.8**	**< 1.5**	**N/A**
				Equalizer Beam, SL				
12	0.4	0.66	0.29	69.6%	1.13	0.55	1.04	12.6
24	0.7	0.60	0.26	70.1%	1.05	0.55	1.03	12.4
32	0.7	0.54	0.27	69.1%	1.01	0.58	1.05	12.3
				Equalizer Beam, BL				
12	0.9	0.64	0.29	72.7%	1.12	0.57	1.06	12.5
24	1.0	0.57	0.26	78.7%	1.03	0.53	1.01	12.4
32	1.1	0.53	0.25	64.8%	1.00	0.54	1.01	12.1
				Radial Arm, SL				
12	0.5	0.62	0.30	61.4%	1.11	0.55	1.03	12.6
24	0.8	0.59	0.27	67.0%	1.07	0.56	1.04	12.1
32	0.6	0.58	0.29	67.5%	1.05	0.58	1.05	11.8
				Radial Arm, BL				
12	1.7	0.64	0.29	68.5%	1.13	0.59	1.07	12.3
24	1.7	0.58	0.26	71.5%	1.06	0.56	1.03	11.9
32	1.1	0.57	0.27	63.7%	1.04	0.53	1.00	11.2
				Rubber Chevron, SL				
12	0.5	0.57	0.28	63.1%	1.04	0.53	1.00	10.6
24	1.0	0.61	0.27	61.5%	1.08	0.54	1.00	10.3
32	1.5	0.58	0.29	48.0%	1.05	0.54	1.00	10.1
				Rubber Chevron, BL				
12	1.8	0.61	0.27	68.0%	1.07	0.55	1.01	9.5
24	1.2	0.54	0.25	74.9%	1.00	0.50	0.95	9.2
32	1.1	0.55	0.27	67.8%	0.98	0.46	0.90	9.2
				Conical Spring, SL				
12	0.5	0.61	0.27	63.2%	1.08	0.47	0.93	9.3
24	1.1	0.51	0.26	65.7%	0.97	0.47	0.93	9.2
32	1.1	0.53	0.24	65.1%	0.95	0.47	0.91	9.1
				Conical Spring, BL				
12	1.8	0.53	0.25	69.9%	1.00	0.46	0.90	7.8
24	0.9	0.48	0.23	73.1%	0.92	0.45	0.86	7.6
32	1.5	0.45	0.22	64.9%	0.85	0.44	0.83	9.5
				Journal Spring, SL				
12	0.5	0.63	0.30	66.4%	1.11	0.56	1.04	11.6
24	0.9	0.59	0.27	73.1%	1.06	0.56	1.04	11.1
32	1.0	0.54	0.25	71.9%	1.00	0.57	1.04	10.9
				Journal Spring, BL				
12	1.0	0.68	0.29	67.2%	1.16	0.61	1.09	11.5
24	1.6	0.61	0.27	76.2%	1.08	0.58	1.05	11.1
32	0.8	0.51	0.24	74.4%	0.96	0.51	0.98	10.7

Table F11. Curving Results 7.5-degree North Spiral Counter-Clockwise Direction

Speed (mph)	Max Roll Angle (deg)	50 ms/3ft Max wheel L/V	6 ft Max truck side L/V	3 ft/50 ms Min vertical wheel load	50 ms/ 3 ft Max axle sum L/V	Max 95% Wheel L/V	Max 95% axle sum L/V	Max Angle of Attack (mrad)
Criterion								
	< 6	< 1.0	< 0.6	> 10%	< 1.5	< 0.8	< 1.5	N/A
Equalizer Beam, SL								
12	0.3	0.60	0.29	78.2%	1.09	0.55	1.03	12.9
24	0.4	0.60	0.27	75.7%	1.08	0.55	1.02	12.6
32	0.7	0.59	0.29	66.0%	1.07	0.57	1.04	12.3
Equalizer Beam, BL								
12	0.5	0.62	0.29	78.8%	1.11	0.57	1.05	12.9
24	1.2	0.61	0.27	77.7%	1.09	0.56	1.03	12.6
32	0.9	0.61	0.31	68.1%	1.09	0.52	0.99	12.3
Radial Arm, SL								
12	0.4	0.61	0.30	78.4%	1.09	0.56	1.04	13.1
24	0.6	0.60	0.27	71.9%	1.09	0.57	1.04	12.7
32	0.9	0.58	0.28	64.7%	1.07	0.57	1.04	12.5
Radial Arm, BL								
12	1.3	0.68	0.30	72.3%	1.16	0.62	1.10	12.8
24	2.4	0.72	0.32	66.3%	1.20	0.59	1.07	12.2
32	0.9	0.59	0.29	68.3%	1.07	0.53	0.99	11.8
Rubber Chevron, SL								
12	0.5	0.61	0.29	73.1%	1.08	0.54	1.00	11.1
24	1.1	0.68	0.26	59.0%	1.16	0.53	0.99	11.0
32	0.8	0.57	0.28	65.7%	1.02	0.53	0.97	10.6
Rubber Chevron, BL								
12	1.7	0.67	0.29	71.9%	1.12	0.58	1.04	9.8
24	2.6	0.76	0.33	65.9%	1.22	0.56	1.02	10.0
32	0.7	0.53	0.24	68.0%	0.99	0.46	0.90	9.6
Conical Spring, SL								
12	0.4	0.52	0.27	76.9%	1.01	0.48	0.95	9.9
24	0.6	0.51	0.24	70.3%	0.97	0.47	0.93	10.0
32	1.0	0.52	0.26	57.8%	0.98	0.49	0.94	10.4
Conical Spring, BL								
12	1.7	0.59	0.24	71.6%	1.08	0.48	0.92	8.8
24	2.4	0.60	0.27	64.9%	1.05	0.47	0.91	8.7
32	0.9	0.51	0.27	70.7%	0.97	0.45	0.83	9.1
Journal Spring, SL								
12	0.4	0.61	0.29	80.1%	1.11	0.57	1.04	12.0
24	0.7	0.60	0.27	75.1%	1.08	0.56	1.04	11.7
32	1.3	0.58	0.26	66.7%	1.07	0.58	1.04	11.4
Journal Spring, BL								
12	1.1	0.66	0.29	75.3%	1.15	0.62	1.09	12.0
24	1.0	0.62	0.27	80.0%	1.10	0.57	1.03	11.5
32	0.6	0.56	0.27	67.8%	1.03	0.51	0.98	11.1

Table F12. Curving Results 7.5-degree Curve Counter-Clockwise Direction

Speed (mph)	Max Roll Angle (deg)	50 ms/3ft Max wheel L/V	6 ft Max truck side L/V	3 ft/50 ms Min vertical wheel load	50 ms/ 3 ft Max axle sum L/V	Max 95% Wheel L/V	Max 95% axle sum L/V	Max Angle of Attack (mrad)
Criterion								
	< 6	< 1.0	< 0.6	> 10%	< 1.5	< 0.8	< 1.5	N/A
Equalizer Beam, SL								
12	0.5	0.67	0.32	78.3%	1.16	0.59	1.08	15.2
24	0.4	0.65	0.28	74.9%	1.14	0.60	1.08	15.1
32	0.8	0.56	0.28	61.0%	1.03	0.63	1.10	15.1
Equalizer Beam, BL								
12	0.5	0.69	0.31	76.0%	1.18	0.61	1.10	15.2
24	1.1	0.62	0.29	76.2%	1.10	0.57	1.05	15.1
32	1.2	0.57	0.28	58.6%	1.06	0.58	1.06	14.6
Radial Arm, SL								
12	0.4	0.69	0.33	75.9%	1.19	0.59	1.07	15.2
24	0.5	0.67	0.30	73.2%	1.17	0.60	1.08	14.8
32	1.1	0.59	0.27	56.0%	1.07	0.62	1.09	14.8
Radial Arm, BL								
12	1.0	0.73	0.33	74.2%	1.22	0.62	1.11	14.9
24	1.9	0.72	0.32	66.7%	1.21	0.61	1.09	14.3
32	1.2	0.58	0.28	64.9%	1.05	0.56	1.04	14.1
Rubber Chevron, SL								
12	0.6	0.70	0.32	75.1%	1.19	0.58	1.05	13.4
24	1.0	0.73	0.29	65.5%	1.20	0.59	1.05	13.3
32	1.5	0.67	0.30	50.4%	1.13	0.60	1.06	13.1
Rubber Chevron, BL								
12	1.2	0.74	0.30	72.0%	1.22	0.58	1.05	12.3
24	2.3	0.69	0.31	66.5%	1.16	0.59	1.05	11.9
32	1.3	0.56	0.26	65.5%	1.03	0.52	0.97	11.8
Conical Spring, SL								
12	0.4	0.63	0.30	79.5%	1.12	0.53	1.01	12.3
24	0.5	0.60	0.26	73.0%	1.10	0.53	1.00	12.3
32	1.2	0.57	0.29	60.5%	1.05	0.53	1.00	12.1
Conical Spring, BL								
12	1.1	0.62	0.29	73.6%	1.11	0.52	0.99	11.0
24	2.1	0.61	0.29	69.4%	1.10	0.53	0.99	10.6
32	1.4	0.52	0.27	61.5%	0.99	0.47	0.91	10.3
Journal Spring, SL								
12	0.4	0.70	0.33	76.7%	1.19	0.60	1.08	14.2
24	0.7	0.65	0.30	73.1%	1.14	0.60	1.08	13.9
32	1.1	0.61	0.27	65.8%	1.10	0.61	1.08	13.8
Journal Spring, BL								
12	0.9	0.74	0.33	70.8%	1.24	0.64	1.13	14.0
24	1.6	0.70	0.31	72.2%	1.19	0.61	1.09	13.7
32	0.7	0.56	0.27	67.8%	1.03	0.54	1.01	13.5

Table F13. Curving Results 10-degree South Spiral Counter-Clockwise Direction

Speed (mph)	Max Roll Angle (deg)	50 ms/3ft Max wheel L/V	6 ft Max truck side L/V	3 ft/50 ms Min vertical wheel load	50 ms/ 3 ft Max axle sum L/V	Max 95% Wheel L/V	Max 95% axle sum L/V	Max Angle of Attack (mrad)
				Criterion				
	< 6	< 1.0	< 0.6	> 10%	< 1.5	< 0.8	< 1.5	N/A
				Equalizer Beam, SL				
12	0.4	0.70	0.34	66.6%	1.17	0.63	1.11	17.8
24	0.5	0.66	0.34	58.9%	1.13	0.63	1.10	17.3
32	0.6	0.62	0.34	45.4%	1.10	0.63	1.10	17.0
				Equalizer Beam, BL				
12	0.8	0.65	0.33	72.4%	1.15	0.62	1.12	17.6
24	0.8	0.61	0.31	60.3%	1.11	0.58	1.07	17.3
32	1.5	0.60	0.31	58.3%	1.08	0.57	1.05	16.5
				Radial Arm, SL				
12	0.5	0.68	0.35	68.2%	1.18	0.63	1.11	17.8
24	0.7	0.68	0.32	64.9%	1.17	0.61	1.09	17.1
32	0.9	0.63	0.31	49.7%	1.12	0.62	1.10	16.3
				Radial Arm, BL				
12	0.9	0.71	0.34	68.1%	1.21	0.64	1.13	17.6
24	2.0	0.65	0.30	66.7%	1.16	0.59	1.08	16.7
32	1.0	0.61	0.30	60.1%	1.09	0.55	1.04	16.1
				Rubber Chevron, SL				
12	0.5	0.67	0.33	66.2%	1.16	0.60	1.08	15.7
24	1.2	0.73	0.30	56.8%	1.21	0.59	1.07	15.2
32	1.8	0.66	0.31	56.5%	1.15	0.59	1.06	14.7
				Rubber Chevron, BL				
12	1.0	0.69	0.32	67.4%	1.17	0.63	1.11	14.4
24	2.2	0.67	0.30	68.1%	1.16	0.56	1.04	13.6
32	1.7	0.62	0.29	56.9%	1.11	0.53	1.00	13.3
				Conical Spring, SL				
12	0.4	0.67	0.32	68.0%	1.16	0.62	1.08	13.8
24	0.8	0.62	0.30	69.5%	1.10	0.59	1.06	13.7
32	0.8	0.63	0.32	48.7%	1.10	0.58	1.05	13.6
				Conical Spring, BL				
12	1.3	0.67	0.31	70.3%	1.18	0.60	1.08	12.6
24	2.1	0.59	0.28	61.9%	1.08	0.55	1.02	12.3
32	1.5	0.56	0.30	59.7%	1.04	0.51	0.99	12.4
				Journal Spring, SL				
12	0.4	0.69	0.35	71.7%	1.19	0.60	1.08	16.6
2	0.9	0.66	0.32	69.8%	1.16	0.59	1.08	16.3
32	0.9	0.61	0.30	55.1%	1.09	0.59	1.07	15.6
				Journal Spring, BL				
12	0.9	0.74	0.35	67.7%	1.25	0.67	1.16	16.5
24	2.0	0.67	0.31	68.5%	1.18	0.62	1.11	16.3
32	0.7	0.55	0.27	60.6%	1.05	0.53	1.02	15.4

Table F14. Curving Results 10-degree North Spiral Counter-Clockwise Direction

Speed (mph)	Max Roll Angle (deg)	50 ms/3ft Max wheel L/V	6 ft Max truck side L/V	3 ft/50 ms Min vertical wheel load	50 ms/ 3 ft Max axle sum L/V	Max 95% Wheel L/V	Max 95% axle sum L/V	Max Angle of Attack (mrad)
				Criterion				
	< 6	**< 1.0**	**< 0.6**	**> 10%**	**< 1.5**	**< 0.8**	**< 1.5**	**N/A**
				Equalizer Beam, SL				
12	0.5	0.68	0.33	78.6%	1.18	0.57	1.07	17.8
24	0.5	0.68	0.29	77.2%	1.18	0.58	1.07	17.4
32	0.5	0.73	0.29	63.9%	1.22	0.61	1.08	16.9
				Equalizer Beam, BL				
12	0.6	0.74	0.32	77.1%	1.25	0.62	1.11	17.7
24	0.7	0.69	0.31	77.5%	1.19	0.57	1.06	17.5
32	0.6	0.61	0.28	63.0%	1.10	0.55	1.03	16.8
				Radial Arm, SL				
12	0.5	0.69	0.34	78.4%	1.20	0.57	1.06	17.5
24	0.6	0.69	0.31	72.7%	1.19	0.58	1.07	16.9
32	0.7	0.72	0.33	63.0%	1.22	0.59	1.07	16.2
				Radial Arm, BL				
12	1.6	0.80	0.35	68.3%	1.31	0.63	1.12	17.3
24	1.3	0.68	0.31	76.3%	1.17	0.58	1.07	16.7
32	0.8	0.61	0.29	64.5%	1.10	0.55	1.03	15.8
				Rubber Chevron, SL				
12	0.5	0.70	0.33	76.4%	1.20	0.57	1.05	15.4
24	1.5	0.81	0.30	61.9%	1.30	0.56	1.04	14.8
32	0.9	0.74	0.32	60.6%	1.23	0.57	1.05	14.5
				Rubber Chevron, BL				
12	1.9	0.78	0.32	68.4%	1.28	0.63	1.11	14.2
24	1.4	0.72	0.28	73.5%	1.20	0.55	1.03	13.5
32	0.9	0.59	0.27	62.4%	1.08	0.51	0.98	13.3
				Conical Spring, SL				
12	0.5	0.69	0.33	78.6%	1.20	0.56	1.05	13.5
24	0.7	0.69	0.32	70.5%	1.19	0.55	1.03	13.2
32	0.7	0.70	0.34	59.7%	1.20	0.54	1.02	13.1
				Conical Spring, BL				
12	2.2	0.73	0.31	65.7%	1.24	0.61	1.10	11.9
24	1.3	0.62	0.28	71.1%	1.12	0.50	0.97	11.8
32	0.9	0.56	0.30	63.3%	1.06	0.48	0.96	12.2
				Journal Spring, SL				
12	0.5	0.71	0.34	79.4%	1.22	0.59	1.08	16.5
24	0.7	0.69	0.32	73.4%	1.19	0.58	1.07	16.2
32	0.7	0.68	0.31	65.9%	1.17	0.59	1.07	15.5
				Journal Spring, BL				
12	0.8	0.78	0.33	74.6%	1.28	0.65	1.15	16.6
24	0.7	0.66	0.30	80.4%	1.16	0.59	1.08	16.3
32	0.4	0.58	0.27	63.4%	1.07	0.53	1.01	15.6

Table F15. Curving Results 10-degree Curve Counter-Clockwise Direction

Speed (mph)	Max Roll Angle (deg)	50 ms/3ft Max wheel L/V	6 ft Max truck side L/V	3 ft/50 ms Min vertical wheel load	50 ms/ 3 ft Max axle sum L/V	Max 95% Wheel L/V	Max 95% axle sum L/V	Max Angle of Attack (mrad)
				Criterion				
	< 6	**< 1.0**	**< 0.6**	**> 10%**	**< 1.5**	**< 0.8**	**< 1.5**	**N/A**
				Equalizer Beam, SL				
12	0.4	0.70	0.33	76.2%	1.21	0.61	1.11	18.4
24	0.5	0.67	0.29	77.9%	1.16	0.63	1.12	18.0
32	0.9	0.68	0.31	64.9%	1.17	0.68	1.16	17.7
				Equalizer Beam, BL				
12	0.5	0.71	0.32	74.3%	1.22	0.64	1.14	18.1
24	1.4	0.68	0.30	70.6%	1.18	0.62	1.12	17.7
32	1.2	0.60	0.30	58.1%	1.10	0.61	1.09	16.8
				Radial Arm, SL				
12	0.4	0.68	0.34	74.0%	1.18	0.60	1.10	18.3
24	0.6	0.67	0.31	75.8%	1.18	0.62	1.12	17.9
32	1.2	0.69	0.30	58.2%	1.18	0.66	1.14	17.4
				Radial Arm, BL				
12	1.1	0.75	0.34	67.4%	1.26	0.66	1.16	18.0
24	0.9	0.67	0.31	75.3%	1.17	0.62	1.11	17.2
32	1.2	0.60	0.29	60.0%	1.09	0.59	1.08	16.5
				Rubber Chevron, SL				
12	0.5	0.68	0.33	74.1%	1.18	0.61	1.10	16.3
24	0.8	0.79	0.30	73.7%	1.29	0.64	1.12	15.8
32	1.2	0.72	0.32	56.7%	1.20	0.62	1.09	15.6
				Rubber Chevron, BL				
12	1.2	0.76	0.31	68.4%	1.25	0.65	1.14	14.9
24	1.2	0.68	0.30	76.6%	1.16	0.59	1.07	14.1
32	1.7	0.63	0.29	56.1%	1.11	0.56	1.03	14.0
				Conical Spring, SL				
12	0.4	0.67	0.33	75.8%	1.18	0.61	1.10	14.7
24	0.7	0.64	0.29	74.0%	1.14	0.60	1.09	14.5
32	1.5	0.66	0.32	53.4%	1.14	0.62	1.10	14.1
				Conical Spring, BL				
12	1.2	0.72	0.32	66.2%	1.22	0.62	1.11	13.7
24	1.1	0.61	0.29	77.1%	1.10	0.57	1.05	13.3
32	1.4	0.54	0.29	55.8%	1.05	0.52	1.00	13.3
				Journal Spring, SL				
12	0.4	0.70	0.34	76.3%	1.20	0.62	1.12	17.2
24	0.8	0.68	0.31	76.3%	1.18	0.62	1.12	17.0
32	1.1	0.64	0.31	61.8%	1.14	0.65	1.13	16.3
				Journal Spring, BL				
12	0.8	0.77	0.35	70.9%	1.27	0.67	1.17	17.1
24	1.8	0.69	0.31	73.1%	1.19	0.64	1.13	16.7
32	0.7	0.58	0.28	62.1%	1.07	0.57	1.06	16.1

Table F16. Curving Results 12-degree South Spiral Counter-Clockwise Direction

Speed (mph)	Max Roll Angle (deg)	50 ms/3ft Max wheel L/V	6 ft Max truck side L/V	3 ft/50 ms Min vertical wheel load	50 ms/ 3 ft Max axle sum L/V	Max 95% Wheel L/V	Max 95% axle sum L/V	Max Angle of Attack (mrad)
				Criterion				
	< 6	**< 1.0**	**< 0.6**	**> 10%**	**< 1.5**	**< 0.8**	**< 1.5**	**N/A**
				Equalizer Beam, SL				
12	0.3	0.74	0.35	67.9%	1.23	0.67	1.16	20.9
24	0.3	0.70	0.33	68.0%	1.19	0.66	1.15	20.5
32	0.5	0.66	0.33	60.3%	1.15	0.68	1.16	20.2
				Equalizer Beam, BL				
12	0.5	0.73	0.35	69.3%	1.23	0.67	1.16	20.8
24	0.7	0.65	0.31	75.1%	1.16	0.62	1.12	20.4
32	1.0	0.61	0.29	62.0%	1.10	0.60	1.09	19.6
				Radial Arm, SL				
12	0.4	0.71	0.38	63.8%	1.21	0.64	1.14	20.4
24	0.4	0.69	0.34	69.4%	1.19	0.65	1.14	19.9
32	0.7	0.68	0.33	59.2%	1.17	0.65	1.14	19.2
				Radial Arm, BL				
12	0.7	0.72	0.37	67.7%	1.22	0.67	1.17	20.1
24	0.8	0.67	0.33	74.3%	1.16	0.62	1.12	19.5
32	0.9	0.62	0.30	63.1%	1.12	0.58	1.07	18.5
				Rubber Chevron, SL				
12	0.4	0.74	0.35	62.0%	1.23	0.64	1.13	18.5
24	0.7	0.73	0.33	68.5%	1.22	0.64	1.12	17.9
32	1.3	0.70	0.34	56.1%	1.18	0.67	1.15	17.4
				Rubber Chevron, BL				
12	0.8	0.73	0.34	69.1%	1.23	0.69	1.18	17.2
24	1.2	0.69	0.33	74.4%	1.18	0.63	1.12	16.3
32	1.8	0.65	0.31	55.0%	1.13	0.59	1.07	15.9
				Conical Spring, SL				
12	0.5	0.79	0.36	64.7%	1.27	0.68	1.16	16.3
24	0.5	0.76	0.35	67.3%	1.23	0.66	1.14	15.4
32	0.9	0.70	0.35	60.4%	1.16	0.63	1.11	15.2
				Conical Spring, BL				
12	0.9	0.77	0.34	70.0%	1.24	0.68	1.17	14.7
24	1.2	0.69	0.32	74.3%	1.15	0.60	1.09	14.6
32	1.2	0.56	0.28	61.6%	1.05	0.54	1.02	14.5
				Journal Spring, SL				
12	0.5	0.68	0.38	69.5%	1.18	0.64	1.14	19.5
24	0.6	0.67	0.34	72.5%	1.17	0.64	1.13	19.1
32	0.8	0.62	0.30	65.8%	1.11	0.63	1.12	18.4
				Journal Spring, BL				
12	1.4	0.80	0.44	60.7%	1.31	0.73	1.23	19.3
24	1.6	0.72	0.38	70.1%	1.22	0.67	1.17	18.9
32	0.9	0.59	0.29	64.8%	1.08	0.59	1.08	18.0

Table F17. Curving Results 12-degree Bunched Spiral Counter-Clockwise Direction

Speed (mph)	Max Roll Angle (deg)	50 ms/3ft Max wheel L/V	6 ft Max truck side L/V	3 ft/50 ms Min vertical wheel load	50 ms/ 3 ft Max axle sum L/V	Max 95% Wheel L/V	Max 95% axle sum L/V	Max Angle of Attack (mrad)
Criterion								
	< 6	< 1.0	< 0.6	> 10%	< 1.5	< 0.8	< 1.5	N/A
Equalizer Beam, SL								
12	0.8	0.95	0.48	55.1%	1.42	0.72	1.19	20.3
24	0.8	0.87	0.46	59.9%	1.34	0.70	1.16	19.8
32	0.9	0.84	0.46	53.2%	1.31	0.69	1.15	19.3
Equalizer Beam, BL								
12	0.8	0.86	0.43	58.7%	1.32	0.66	1.17	20.4
24	1.0	0.80	0.42	65.6%	1.27	0.63	1.13	19.9
32	1.2	0.72	0.39	61.0%	1.18	0.61	1.10	19.0
Radial Arm, SL								
12	0.7	0.74	0.39	57.4%	1.21	0.59	1.09	19.9
24	0.9	0.70	0.39	53.1%	1.17	0.61	1.11	19.3
32	1.0	0.71	0.40	52.2%	1.17	0.62	1.11	18.4
Radial Arm, BL								
12	0.9	0.71	0.36	59.6%	1.21	0.67	1.17	20.0
24	1.6	0.70	0.35	60.7%	1.19	0.66	1.16	19.3
32	2.5	0.69	0.38	48.6%	1.18	0.65	1.15	18.3
Rubber Chevron, SL								
12	0.8	0.76	0.39	53.8%	1.21	0.61	1.10	18.2
24	1.3	0.73	0.39	45.9%	1.17	0.61	1.10	17.5
32	1.7	0.74	0.40	37.2%	1.18	0.61	1.09	16.8
Rubber Chevron, BL								
12	1.0	0.76	0.34	59.5%	1.25	0.69	1.18	17.2
24	1.7	0.74	0.35	61.4%	1.22	0.67	1.16	16.6
32	2.7	0.70	0.34	48.8%	1.18	0.65	1.13	15.9
Conical Spring, SL								
12	0.8	0.72	0.37	53.9%	1.16	0.60	1.10	15.7
24	0.8	0.64	0.36	54.8%	1.14	0.60	1.09	15.1
32	0.9	0.67	0.38	47.6%	1.10	0.58	1.07	14.7
Conical Spring, BL								
12	1.0	0.67	0.33	57.7%	1.17	0.64	1.14	14.3
24	1.2	0.64	0.31	64.2%	1.14	0.61	1.10	13.8
32	2.3	0.62	0.32	50.5%	1.11	0.57	1.06	13.7
Journal Spring, SL								
12	0.8	0.69	0.37	64.1%	1.16	0.61	1.12	19.0
24	0.8	0.66	0.36	62.4%	1.14	0.62	1.11	18.6
32	1.0	0.66	0.36	59.4%	1.12	0.63	1.11	17.9
Journal Spring, BL								
12	1.1	0.75	0.38	64.8%	1.25	0.71	1.21	19.0
24	1.6	0.72	0.37	71.4%	1.22	0.68	1.17	18.6
32	1.3	0.63	0.31	58.2%	1.12	0.60	1.09	17.9

Table F18. Curving Results 12-degree Curve Counter-Clockwise Direction

Speed (mph)	Max Roll Angle (deg)	50 ms/3ft Max wheel L/V	6 ft Max truck side L/V	3 ft/50 ms Min vertical wheel load	50 ms/ 3 ft Max axle sum L/V	Max 95% Wheel L/V	Max 95% axle sum L/V	Max Angle of Attack (mrad)
				Criterion				
	< 6	< 1.0	< 0.6	> 10%	< 1.5	< 0.8	< 1.5	N/A
				Equalizer Beam, SL				
12	0.3	0.67	0.35	77.2%	1.18	0.63	1.13	22.5
24	0.3	0.65	0.31	82.6%	1.16	0.66	1.16	22.2
32	0.7	0.61	0.29	61.8%	1.11	0.73	1.21	21.8
				Equalizer Beam, BL				
12	0.6	0.71	0.35	69.7%	1.21	0.69	1.19	22.4
24	0.9	0.70	0.32	76.7%	1.20	0.68	1.18	21.9
32	0.8	0.58	0.28	63.6%	1.08	0.63	1.12	21.5
				Radial Arm, SL				
12	0.5	0.64	0.36	72.5%	1.15	0.62	1.12	21.9
24	0.5	0.65	0.34	78.7%	1.15	0.64	1.14	21.5
32	0.9	0.63	0.33	59.2%	1.13	0.68	1.18	21.1
				Radial Arm, BL				
12	0.5	0.70	0.36	67.5%	1.21	0.67	1.18	21.7
24	1.1	0.66	0.33	76.7%	1.16	0.64	1.14	21.0
32	2.0	0.62	0.30	49.3%	1.12	0.64	1.13	19.9
				Rubber Chevron, SL				
12	0.5	0.67	0.35	72.1%	1.17	0.63	1.13	20.0
24	0.7	0.70	0.32	73.3%	1.20	0.66	1.15	19.5
32	1.5	0.69	0.34	54.6%	1.18	0.69	1.18	19.1
				Rubber Chevron, BL				
12	0.7	0.73	0.34	66.3%	1.23	0.69	1.18	18.7
24	1.1	0.64	0.30	79.2%	1.14	0.63	1.12	18.0
32	2.3	0.65	0.30	50.7%	1.13	0.62	1.11	17.3
				Conical Spring, SL				
12	0.5	0.65	0.36	72.5%	1.16	0.64	1.14	18.3
24	0.5	0.65	0.32	70.9%	1.15	0.64	1.13	18.1
32	1.0	0.66	0.34	60.4%	1.16	0.66	1.15	17.7
				Conical Spring, BL				
12	0.6	0.70	0.33	70.8%	1.20	0.67	1.17	17.2
24	0.9	0.63	0.31	81.6%	1.13	0.62	1.11	16.7
32	2.0	0.61	0.32	50.6%	1.11	0.59	1.08	16.5
				Journal Spring, SL				
12	0.7	0.67	0.37	73.0%	1.17	0.64	1.15	21.1
24	0.8	0.66	0.34	77.5%	1.17	0.65	1.15	20.7
32	0.8	0.61	0.30	67.3%	1.11	0.68	1.17	20.2
				Journal Spring, BL				
12	1.6	0.80	0.44	60.7%	1.31	0.77	1.28	20.7
24	1.5	0.69	0.34	77.1%	1.18	0.66	1.16	20.3
32	0.9	0.59	0.29	60.2%	1.08	0.59	1.09	19.6

Appendix G.
Wheel Load Equalization Results

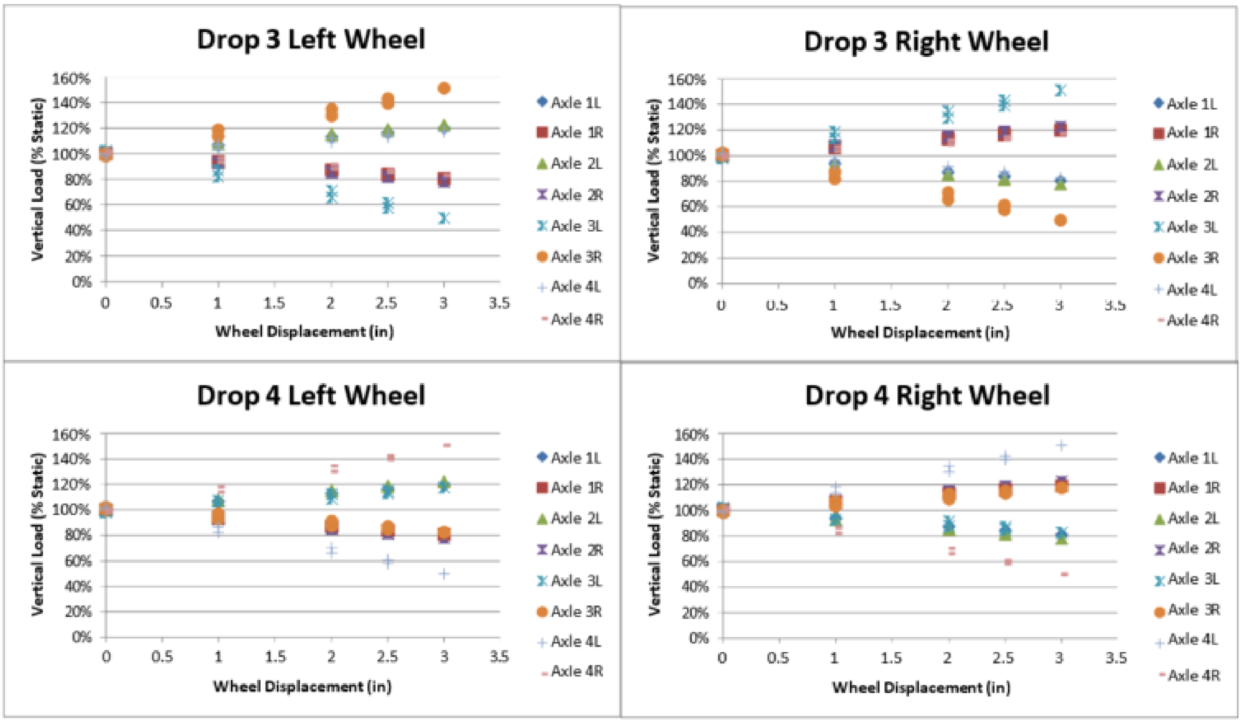

Figure G1. Equalizer Beam, Single-Level Car, Wheel Drop Results, Axles 3 & 4

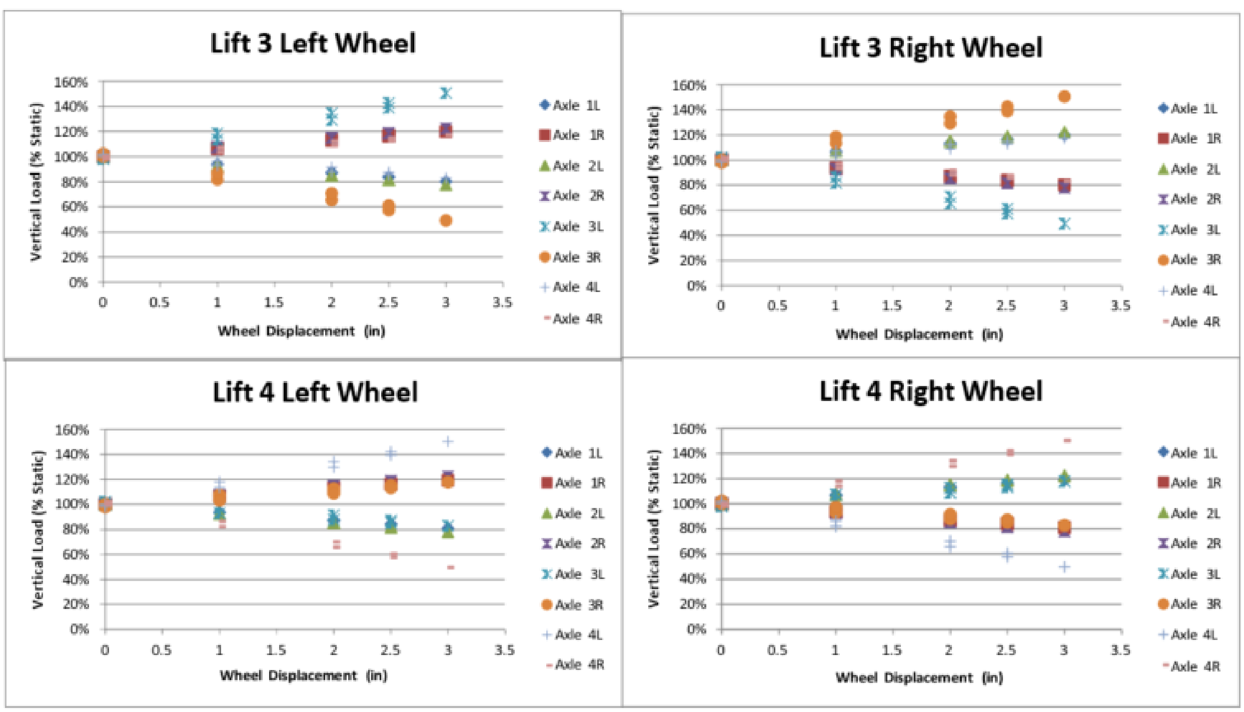

Figure G2. Equalizer Beam, Single-Level Car, Wheel Lift Results, Axles 3 & 4

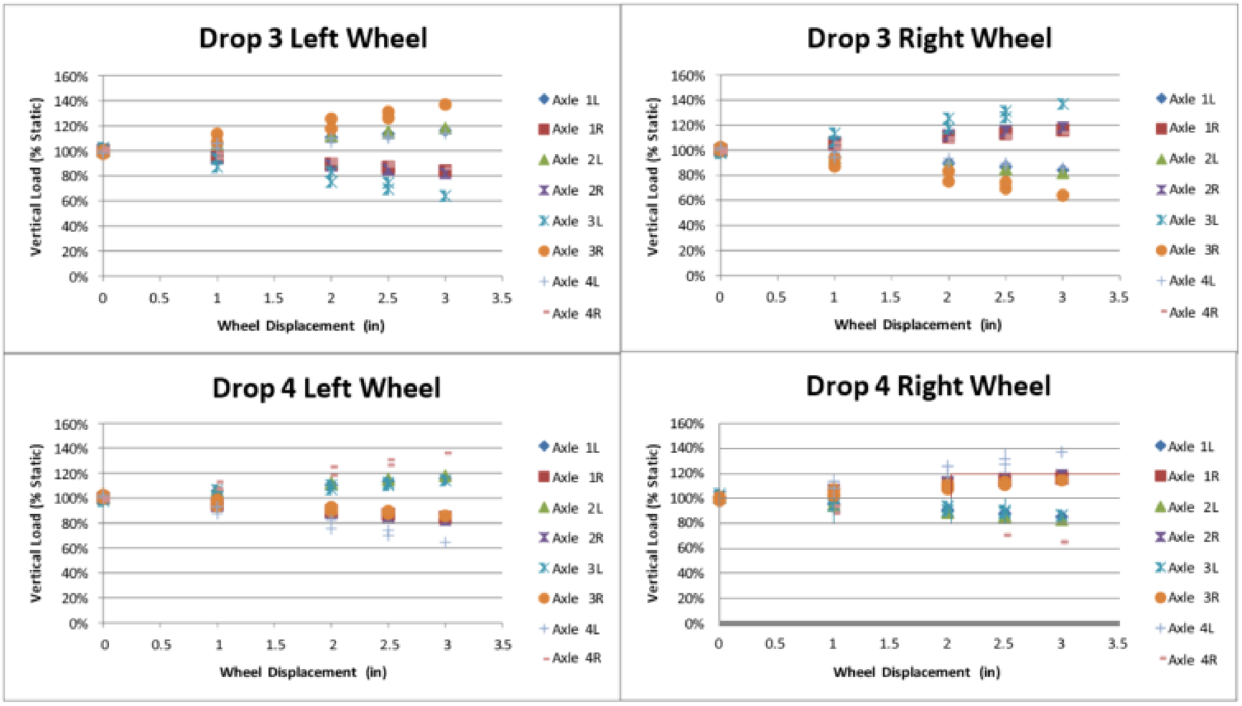

Figure G3. Equalizer Beam, Bi-Level Car, Wheel Drop Results, Axles 3 & 4

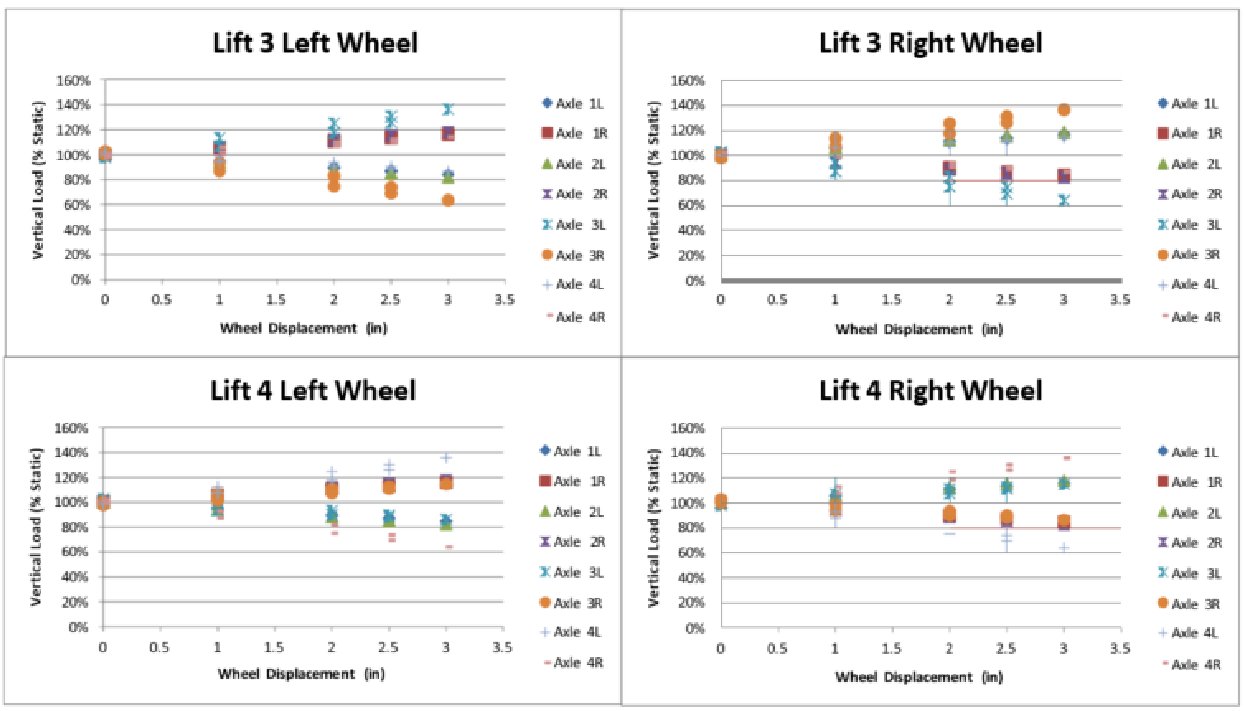

Figure G4. Equalizer Beam, Bi-Level Car, Wheel Lift Results, Axles 3 & 4

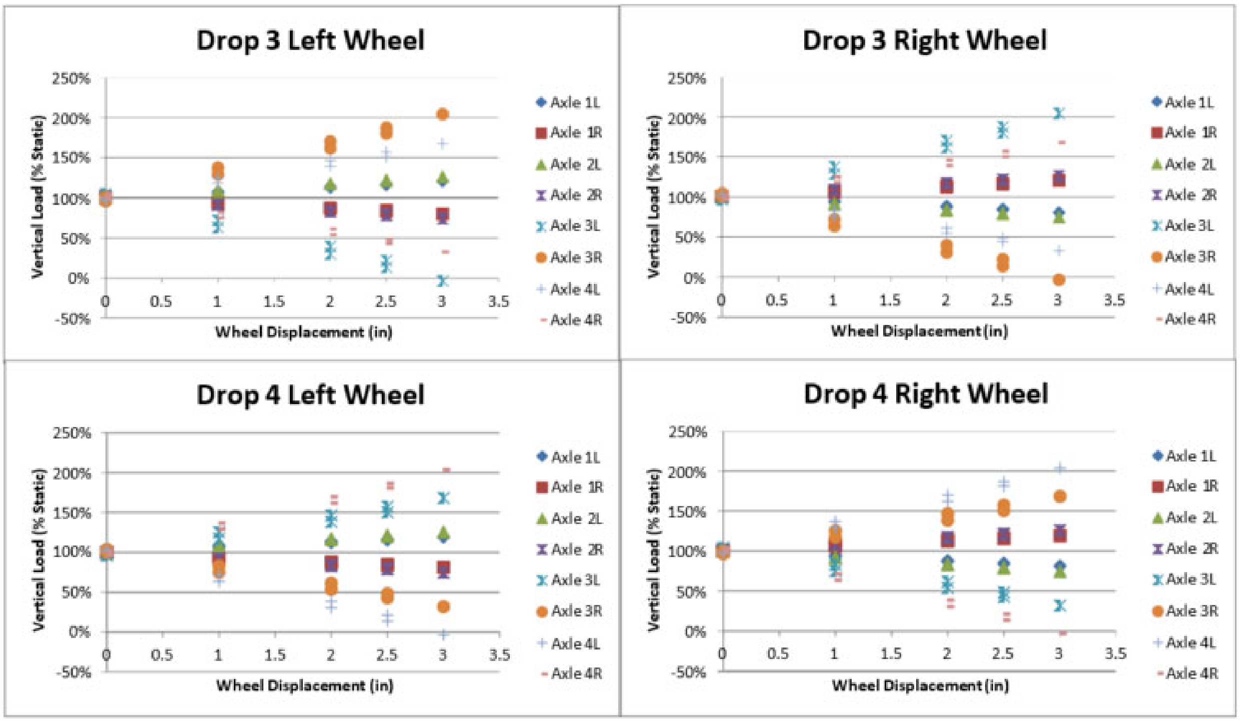

Figure G5. Journal Spring, Single-Level Car, Wheel Drop Results, Axles 3 & 4

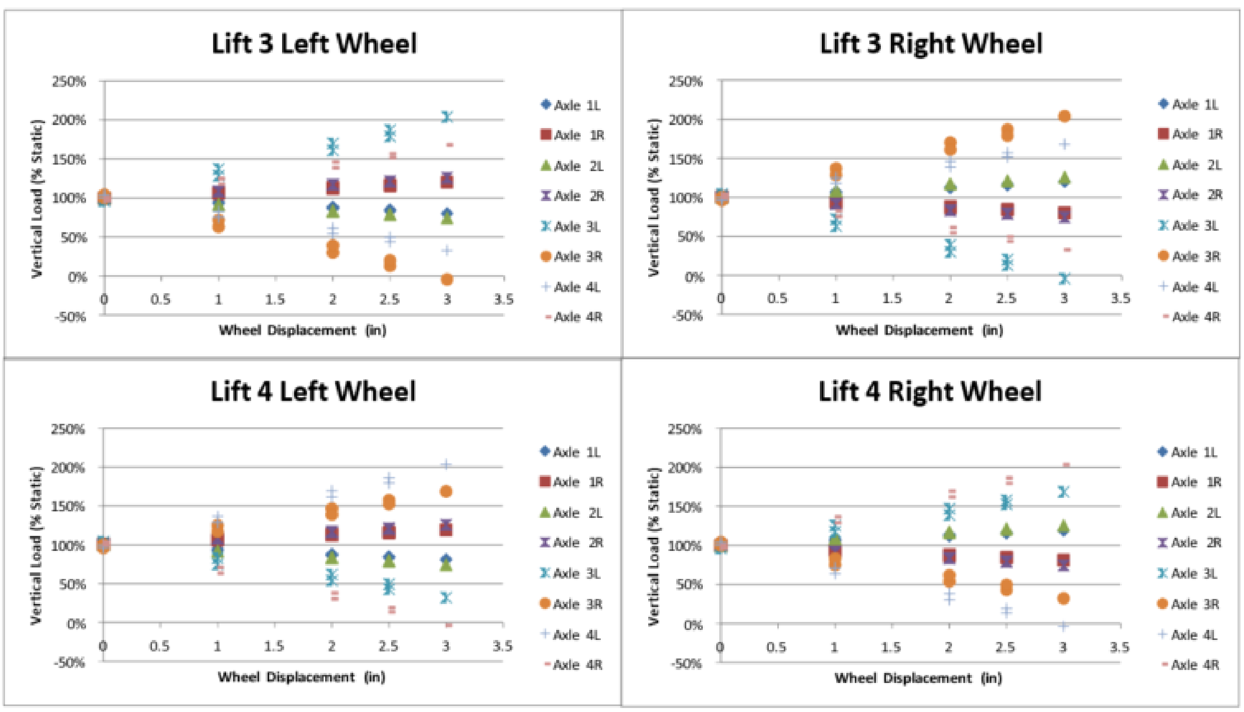

Figure G6. Journal Spring, Single-Level Car, Wheel Lift Results, Axles 3 & 4

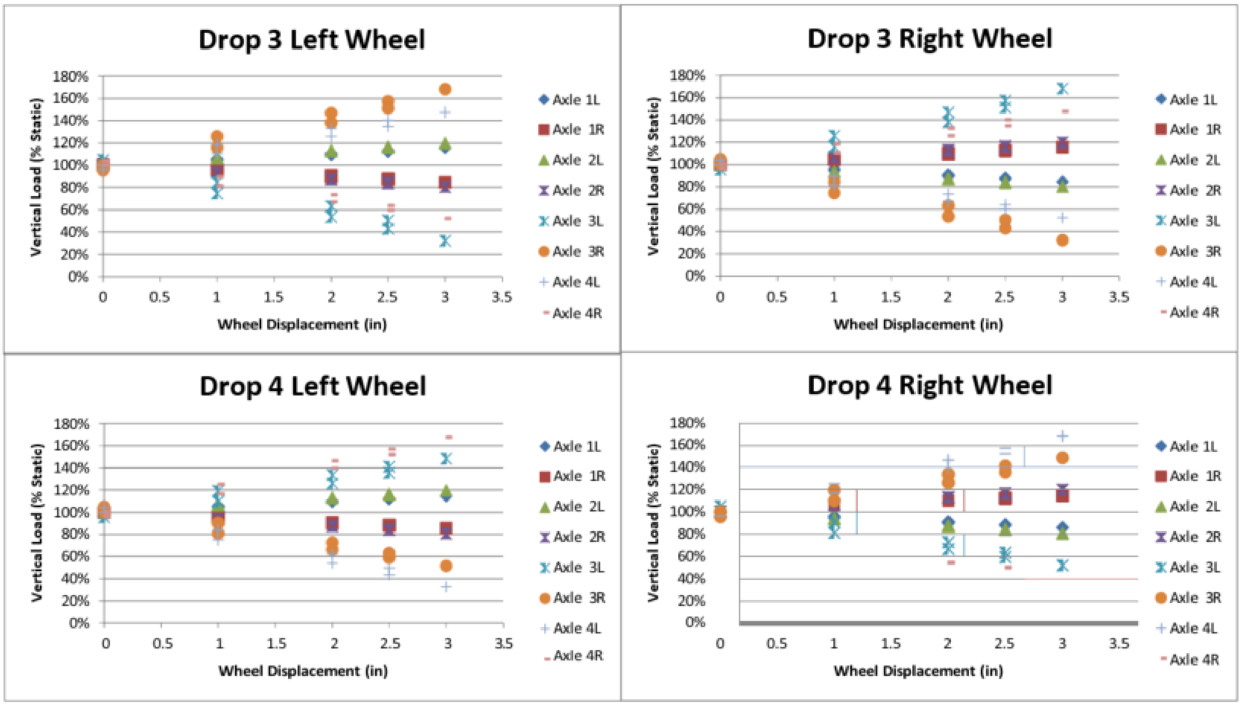

Figure G7. Journal Spring, Bi-Level Car, Wheel Drop Results, Axles 3 & 4

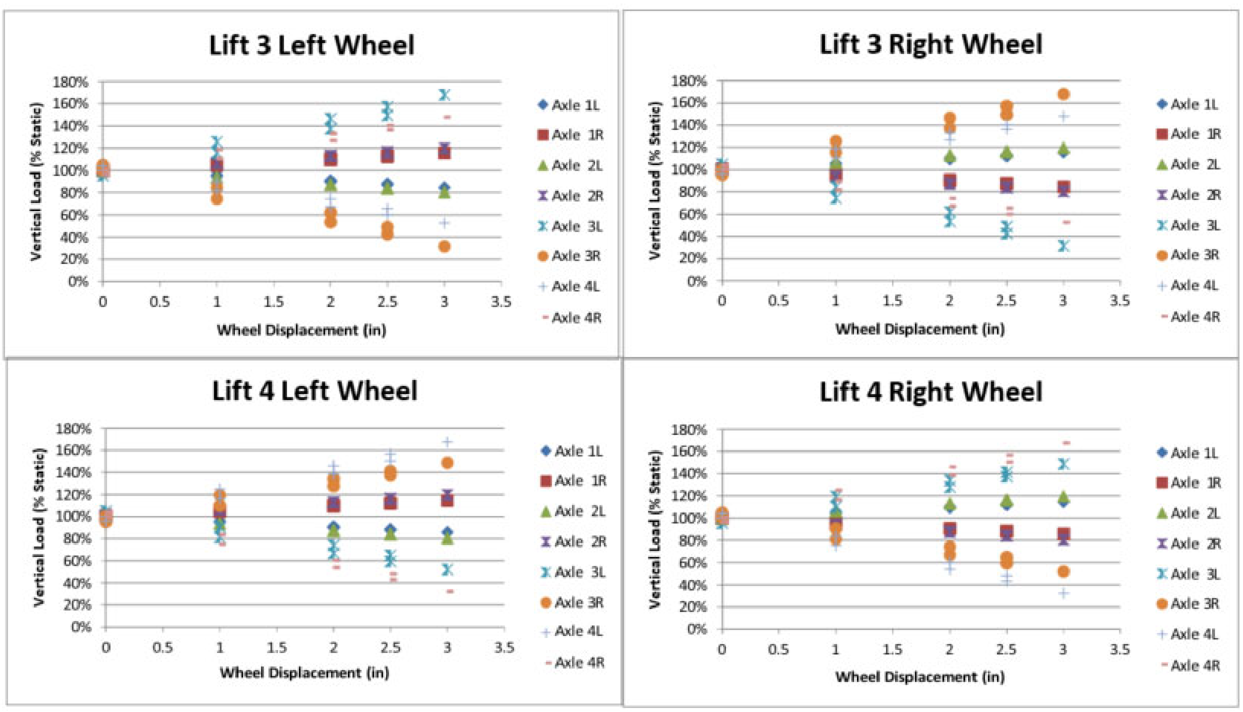

Figure G8. Journal Spring, Bi-Level Car, Wheel Lift Results, Axles 3 & 4

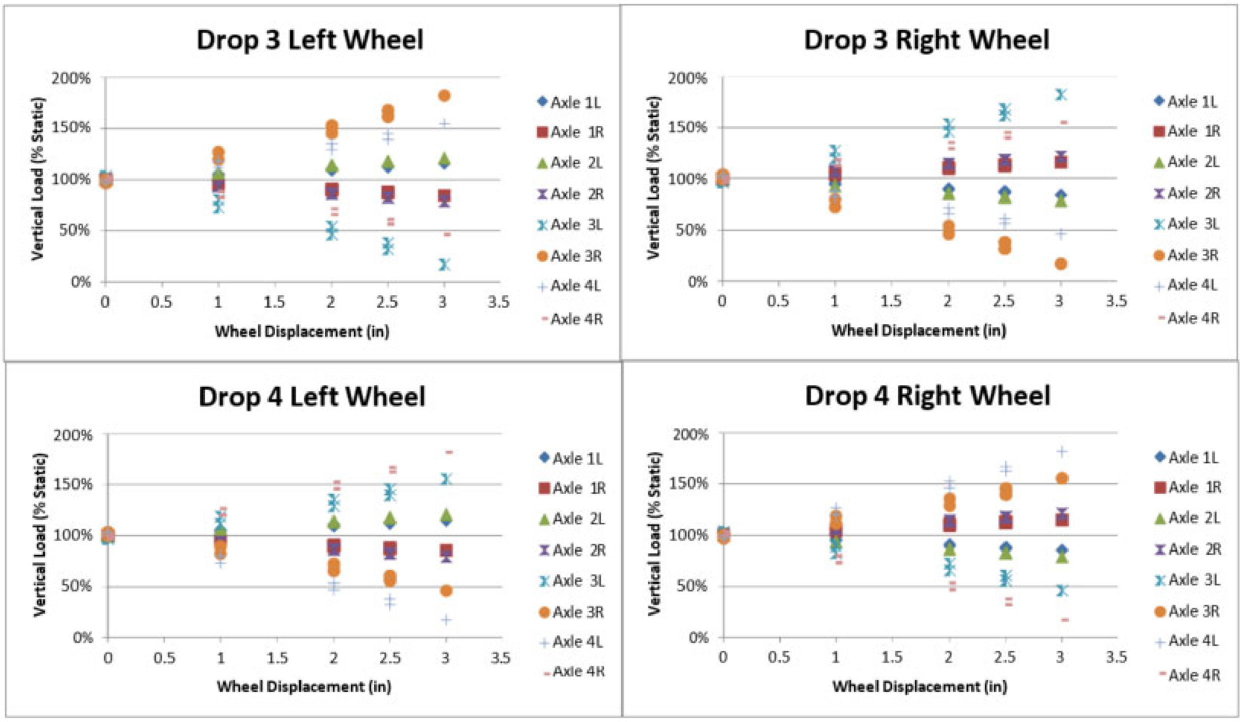

Figure G9. Radial Arm, Single-Level Car, Wheel Drop Results, Axles 3 & 4

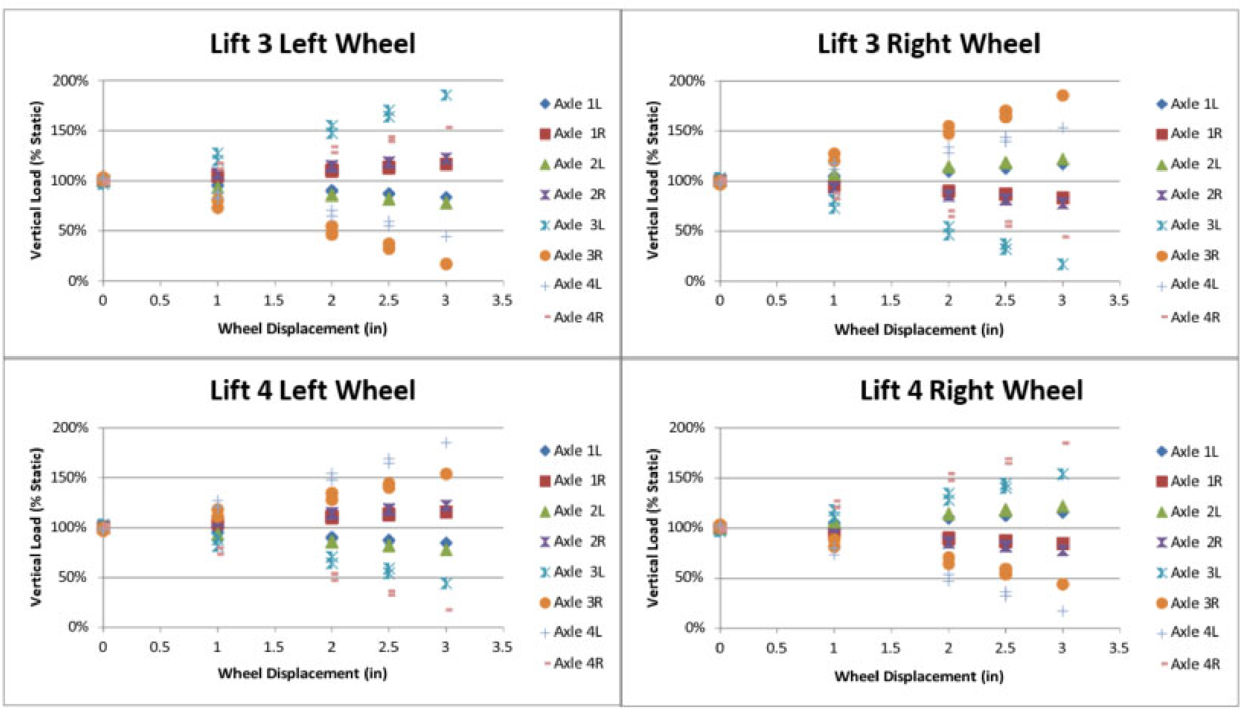

Figure G10. Radial Arm, Single-Level Car, Wheel Lift Results, Axles 3 & 4

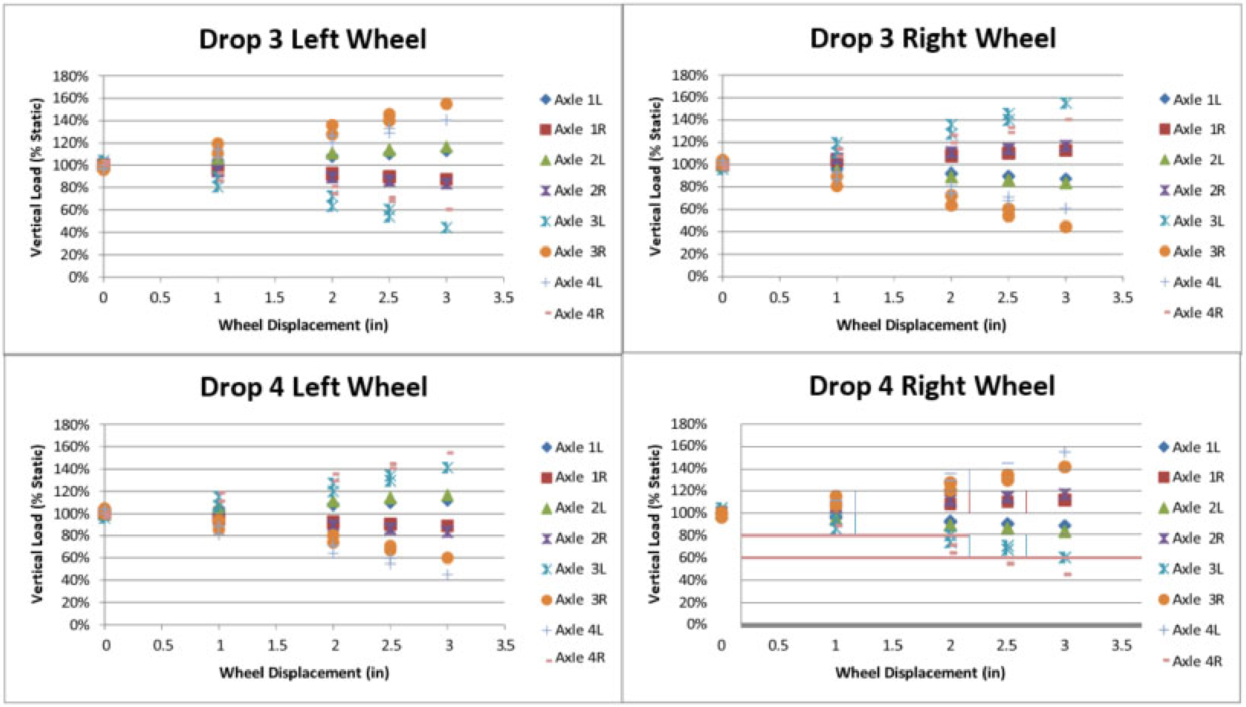

Figure G11. Radial Arm, Bi-Level Car, Wheel Drop Results, Axles 3 & 4

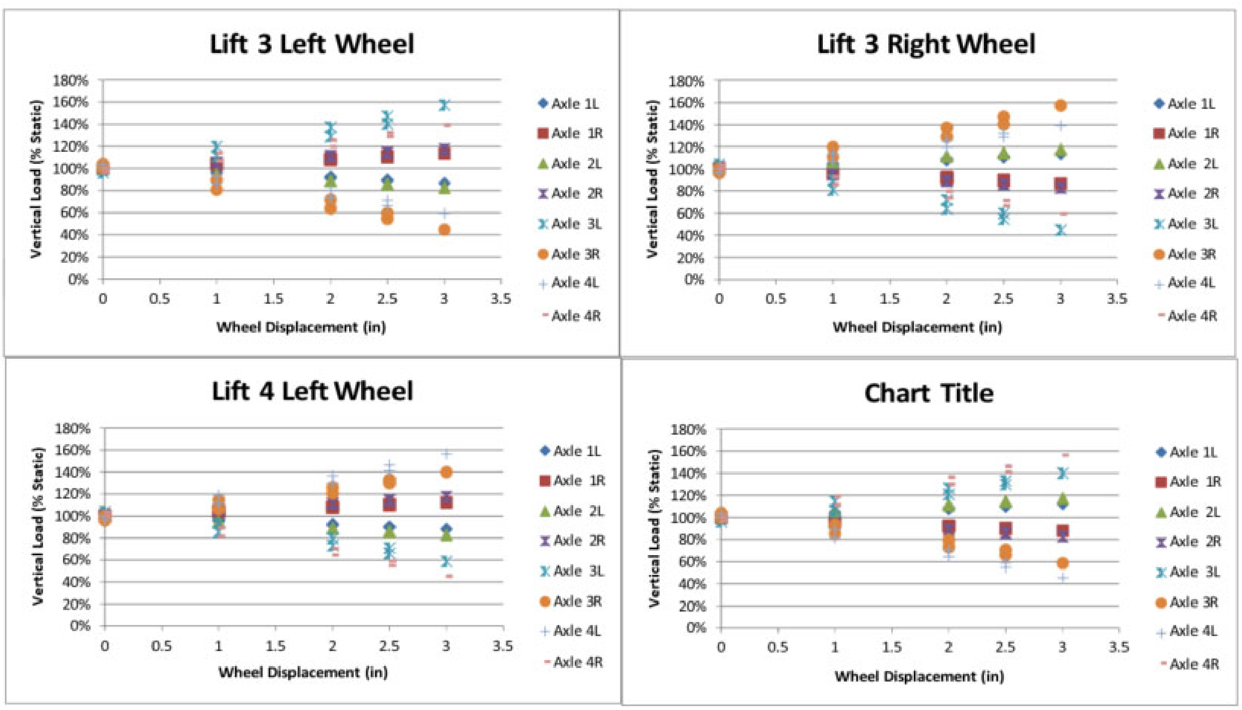

Figure G12. Radial Arm, Bi-Level Car, Wheel Lift Results, Axles 3 & 4

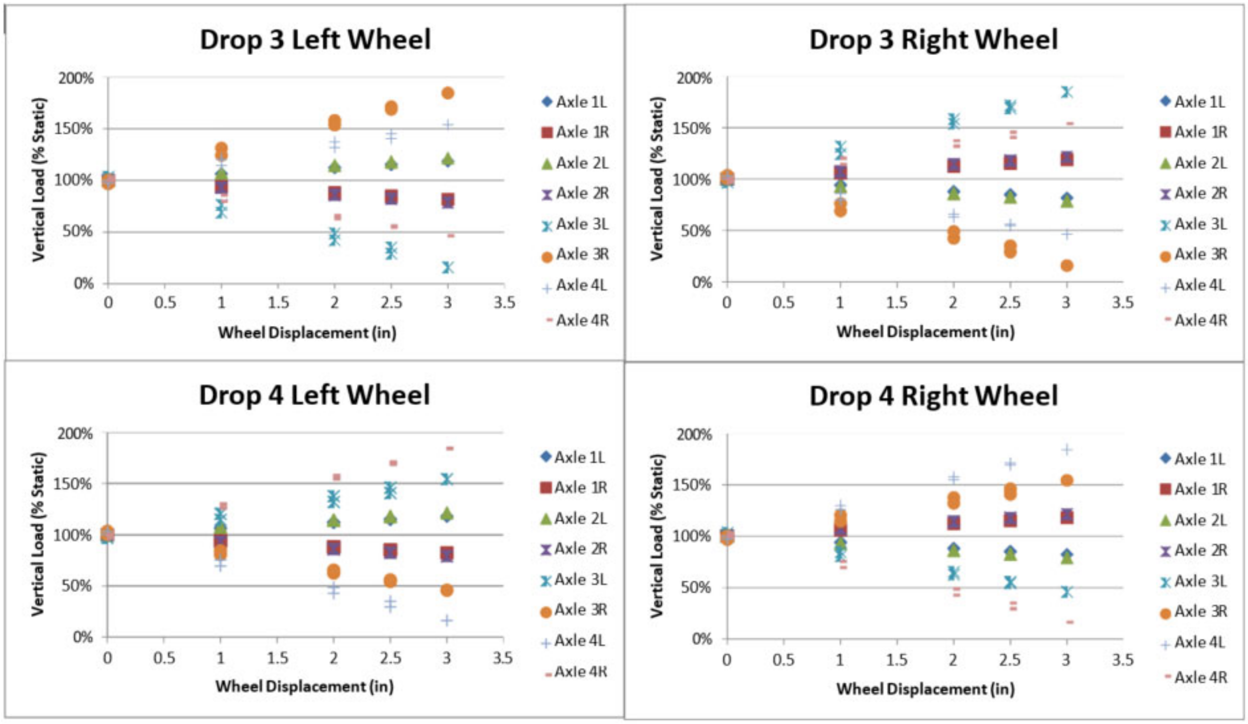

Figure G13. Rubber Chevron, Single-Level Car, Wheel Drop Results, Axles 3 & 4

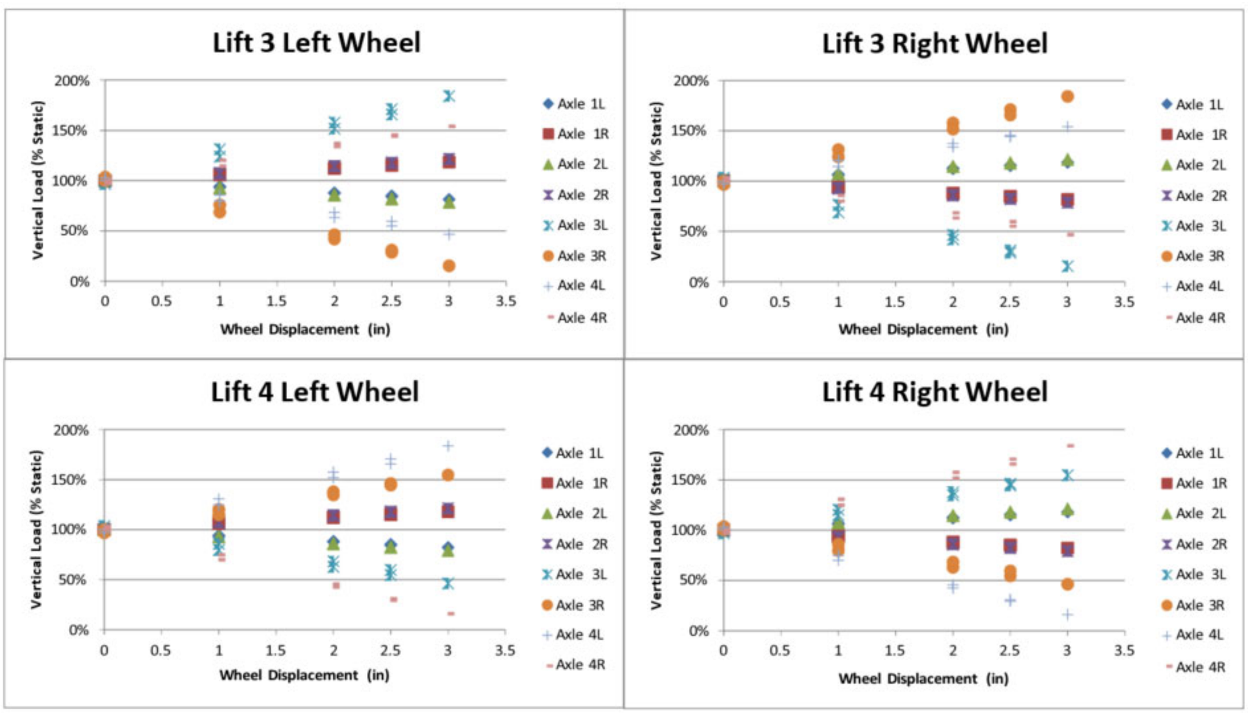

Figure G14. Rubber Chevron, Single-Level Car, Wheel Lift Results, Axles 3 & 4

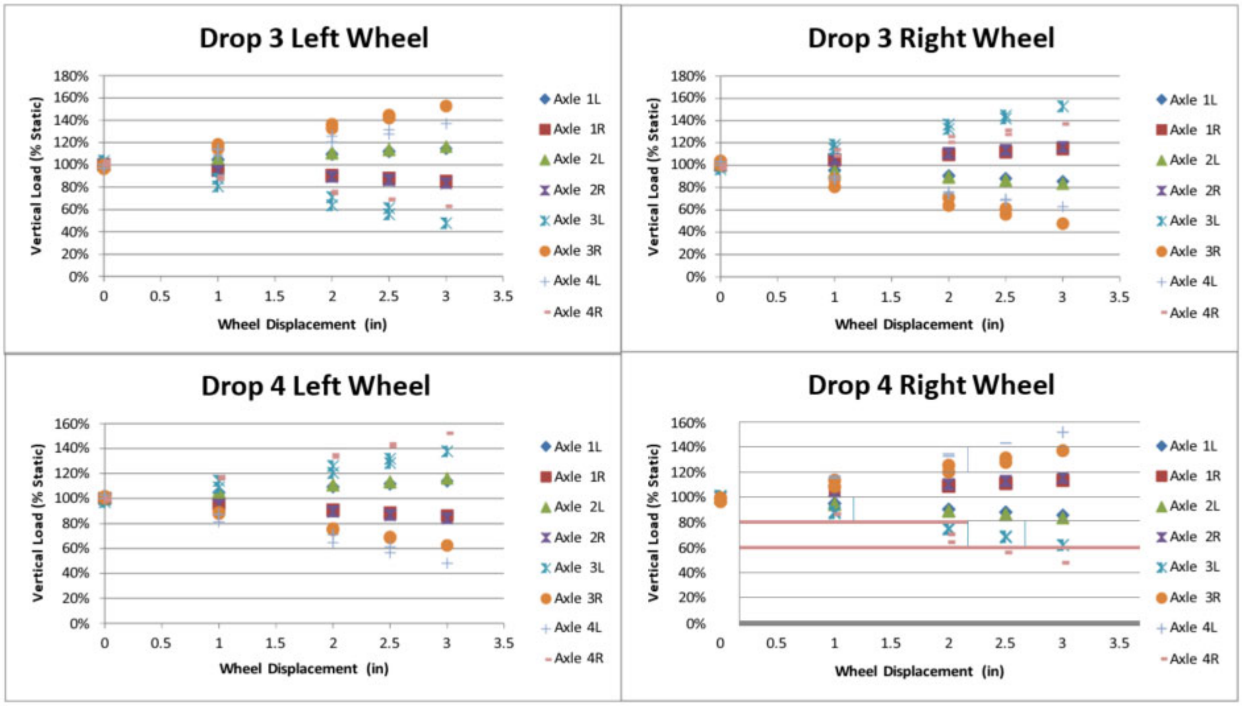

Figure G15. Rubber Chevron, Bi-Level Car, Wheel Drop Results, Axles 3 & 4

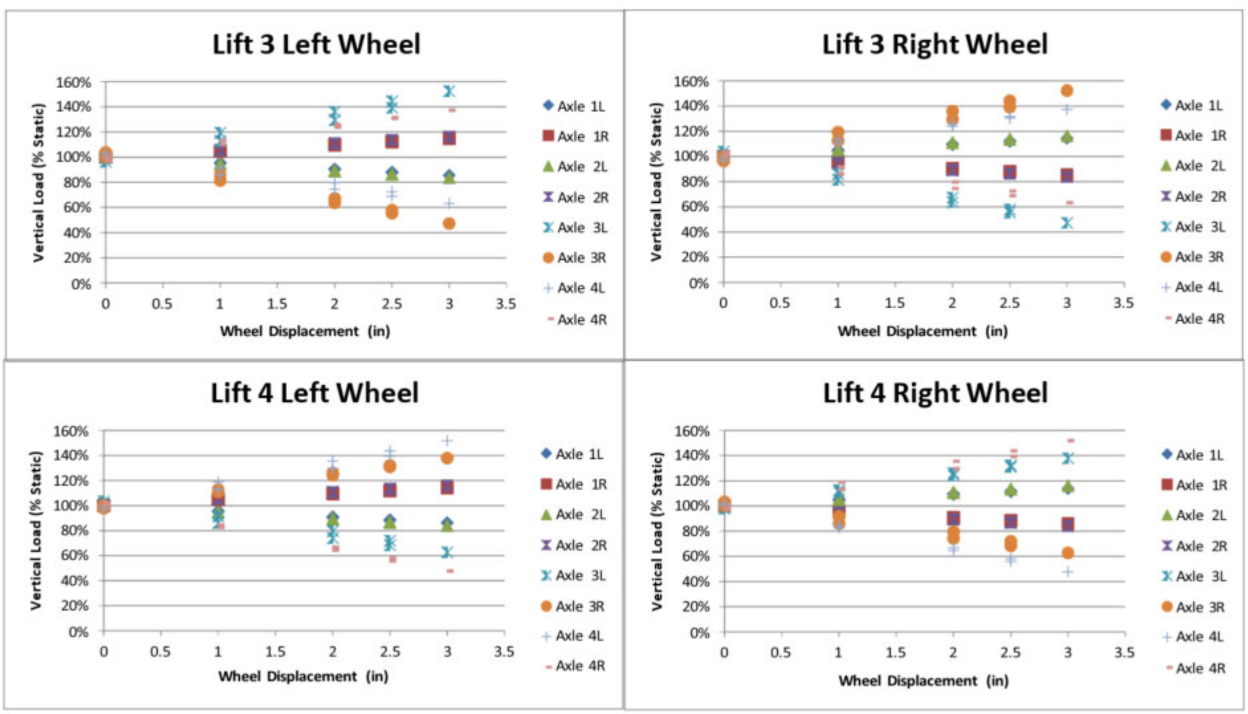

Figure G16. Rubber Chevron, Bi-Level Car, Wheel Lift Results, Axles 3 & 4

Appendix H.
NUCARS® Mathematical Models (SYS Files)

System file (.SYS) for NUCARS Version 2.0
==

TTX 70 ton 89 Flat Bi-Level Rack CCSB - Const. friction damping 04/08/96

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

```
 Body #   ' 15 Char Name  '          C.G. Posn in X, Y, & Z00
          No. & DoF List             Mass, Roll, Pitch, & Yaw Inertia00
---------------------------------------------------------------------------
\BODY DATA
   19
! Combined C.G.. form hand calculations of Rack and Autos at 82.1"
! Hand calculations the Car/Rack c.g. location (No Autos) c.g. 78.6"
! Autorack weight from FRA report FRA/ORD-81/75.2 98,400 lb.0= 254.86
! Roll, Pitch and Yaw Inertias verified by hand calculations and need
! to be verified by hand excitation
! 208.86 *0386.09 = 80,638.75
        1     ' Full Main Body'      -430.000 0.00  78.6
           8   1 2 3 4 5 6 7 8      208.8600 3.40E050  24.3E06   24.4E06
!    1     ' Full Main Body'     -430.000 0.00  78.6
!       6   1 2 3 4 5 6          208.860  3.40E05   24.3E06   24.4E06
!Ratio 100-ton to 70 ton0axles i.e.(33/36)*3.78 2.76E03 x.x 2.76E030
! From TTD report 70-ton0bolsters weights 3.00
!                                3.46   2.530E03  1.62E2    2.530E03
! 3.46 * 386.09 = 1335.87
     2     'Leading Bolster'      -34.000 0.0  16.50
        6  1  2  3  4  5  6      3.46   2.530E03  1.62E2    2.530E03
     3     'Trailing Bolster'     -826.000 0.0  16.5
        6  1  2  3  4  5  6      3.46   2.530E03  1.62E2    2.530E03
!Ratio 100-ton to 70 ton axles0i.e.(33/36)*2.98 0.0 1.37E03 1.37E030
!                                2.73   0.0       1.256E03  1.256E03
! 2.73 * 386.09 = 1054.03
     4     'Lead Lft Sframe'      -34.0  39.0  16.500
        5    1  2  3  5  6       2.73   0.0       1.256E03  1.256E03
     5     'Lead Rgt Sframe'      -34.0 -39.0  16.500
        5    1  2  3  5  6       2.73   0.0       1.256E03  1.256E03
     6     'Trail Lt Sframe'     -826.0  39.0  16.500
        5    1  2  3  5  6       2.73   0.000     1.256E03  1.256E03
     7     'Trail Rt Sframe'     -826.0 -39.00016.50
        5    1  2  3  5  6       2.73   0.00      1.256E03  1.256E030
! Ratio 100-ton to 70 ton axles i.e.(33/36)*7.73 5.89E03 2.50E03 5.89E030
!                          7.09   5.40E03   2.29E03   5.40E03
! 7.09 *0386.09 = 2737.38
     8     '00Axle number 1 '       0.0   0.0  16.5
        5  1  2  3  4  6          7.09    5.40E03   2.29E03   5.40E03
     9     '00Axle number 2 '     -68.000 0.0  16.50
        5  1  2  3  4  6          7.0900 5.40E03   2.29E03   5.40E03
    10     '0 Axle number 30'    -792.000 0.0  16.50
        5  1  2  3  4  6          7.0900 5.40E03   2.29E03   5.40E03
    11     ' Axle number 4 '     -860.000 0.0  16.50
        5  1  2  3  4  6          7.0900 5.40E03   2.29E03   5.40E03
! Weight of bolsters, side frames and wheel sets
! Total Weight of Trucks  46.2 * 386.09 = 17837.4 lb.
! Total Autorack weight from FRA report FRA/ORD-81/75.2 98,400 lb. = 254.86
! Flat car0+ Rack0weight 98400-17837.4 = 80562.650= 208.66
! Total Autorack Weight 129,000 lb.
! Auto weights 0 = 129,000- 98,400 = 30,600 lb.
```

```
!
!
  12    'Car 1A Bot Row'      -20.5ee 0.0  70.0e
        6    1  2  3  4  5  6   7.595  694    2310    1840
! 4568 lb.
  13    'Trk 2A Bot Row'     -235.0ee 0.0  70.0e
        6    1  2  3  4  5  6  11.722 1735ee  5834    4650
! 4218 lb.
  14    'Trk 3A Bot Row'     -592.0ee 0.0  70.0e
        6    1  2  3  4  5  6  10.817 1615    5387    4294
! 2975 lb.
  15    'Car 4A Bot Row'     -808.5ee 0.0  70.0e
        6    1  2  3  4  5  6   7.595  694    2310    1840
! 3656 lb.
  16    'Trk 1B Top Row'      -23.0ee 0.0 157.0e
        6    1  2  3  4  5  6   9.359 1400    4670    3720
! 3904 lb.
  17    'Trk 2B Top Row'     -325.0ee 0.0 157.0e
        6    1  2  3  4  5  6  10.001 1495    4985    3975
! 4151 lb.
  18    'Trk 3B Top Row'     -551.5ee 0.0 157.0
        6    1  2  3  4  5  6  10.644 1590    5300    4226
! 4151 lb.
  19    'Trk 4B Top Row'     -800.0ee 0.0 157.0e
        6    1  2  3  4  5  6  10.644 1590    5300    4226

! Total of all Auto's 30600.00ee
```

For all bodies with flexible modes, give the position of the body geometric center, in the X direction from the datum, its length, and the natural frequencies (Hz) and damping ratios in twist, vertical, and lateral bending.

```
  Body #    X-Posnee  X-Lengthee Nat Frequenciese    Damping Ratios
-----------------------------------------------------------------------------
!eeAutorack Flexible Frequencies from FRA report FRA/ORD-81/75.2
\FLEXIBLE MODESee
   1        -430.0  1435.0ee    6.33   8.00 11.16   0.05   0.17  0.05
```

The above frequencies were used to get the proper output frequencies listed below,

```
Note: NUCARS uses a free beam and this is a simlpy supported beam
   1        -430.0  1068.0      6.47   4.48  8.63   0.05   0.05  0.05
```

Give the number of connections, then for each, identify a name, in single quotes and of up to 20 characters, numbers for the bodies at each end, 0 for an earth in local track coords., a position relative to the chosen datum,
a number indicating the degree of freedom, translational 1,2,3 or rotational 4,5,6, in x,y,z resp., including 2 for lateral wheel motion, and the type:

1 - parallel pair of spring and damper characteristics
2 - series pair of spring and damper characteristics
3 - device with hysteresis between 2 PWL characteristics, e.g. carriage spring or load sensitive suspension
4 - lateral/longitudinal suspension of the wheel on rail
5 - connection force as a history of the distance moved

and the identification number for each of type 1, 2 and 3, the axle number for type 4, input function number for type 5.

Note - single characteristics are treated as parallel pairs with the missing characteristic set to zero in the subsequent table.

```
------------------------------------------------------------------------------------
\CONNECTION DATA
141
! Longitudinal car body/center plate to bolster connections
   1   'Ld CB-Bolster  '    1    1   2   -34.022  0.0     22.67   1    1
   2   'Tr CB-Bolster  '    1    1   3  -826.022  0.0     22.67   1    1
! Long., Lateral and Yaw at the bolster to side frame connections
   3   'Ld L Bol-SFrame'   1.1   2   4   -34.0    39.0     16.5 3 1 2 6 1 2 8
   4   'Ld R Bol-SFrame'   1.1   2   5   -34.0   -39.022   16.5 3 1 2 6 1 2 8
   5   'Tr L Bol-SFrame'   1.1   3   6  -826.022 39.02     16.5 3 1 2 6 1 2 8
   6   'Tr R Bol-SFrame'   1.1   3   7  -826.0   -39.022   16.5 3 1 2 6 1 2 8
! Vertical and rotational side frame to axle connections using a line friction
! element
   7   'SdFrame-Ax 1 L'   6.2   4   8     0.0     39.0     22.5   3 6   5
   8   'SdFrame-Ax 1 R'   6.2   5   8     0.0    -39.022   22.5   3 6   5
   9   'SdFrame-Ax 2      6.2   4   9   -68.022  39.022    22.5   3 6   5
  10   'SdFrame-Ax 2      6.2   5   9   -68.022 -39.022    22.5   3 6   5
  11   'SdFrame-Ax 3 L'   6.2   6  10  -792.022  39.022    22.5   3 6   5
  12   'SdFrame-Ax 3 R'   6.2   7  10  -792.022 -39.022    22.5   3 6   5
  13   'SdFrame-Ax 4 L'   6.2   6  11  -860.022  39.022    22.5   3 6   5
  14   'SdFrame-Ax 4 R'   6.2   7  11  -860.022 -39.022    22.5   3 6   5
! Lateral car body/center plate to bolster connections
  15   'Ld CB-Bolster '   1.1   1   2   -34.0     0.0     22.67   2 2 6 1 15
  16   'Tr CB-Bolster '   1.1   1   3  -826.022   0.0     22.67   2 2 6 1 15
! Longitudinal and lateral side frame to axle multi-connections
  17   'Ld L SF-LdAxle'   1.1   4   8     0.0    39.0     22.5  2 1 2   1 1
  18   'Ld L SF-TrAxle'   1.1   4   9   -68.022  39.0     22.5  2 1 2   1 1
  19   'Ld R SF-LdAxle'   1.1   5   8     0.022 -39.022   22.5  2 1 2   1 1
  20   'Ld R SF-TrAxle'   1.1   5   9   -68.022 -39.022   22.5  2 1 2   1 1
  21   'Tr L SF-LdAxle'   1.1   6  10  -792.022  39.022   22.5  2 1 2   1 1
  22   'Tr L SF-TrAxle'   1.1   6  11  -860.022  39.022   22.5  2 1 2   1 1
  23   'Tr R SF-LdAxle'   1.1   7  10  -792.022 -39.022   22.5  2 1 2   1 1
  24   'Tr R SF-TrAxle'   1.1   7  11  -860.022 -39.022   22.5  2 1 2   1 1
! Vertical and rotational connections for center plates using a line friction
! element
  25   'Ld CB-Bolster F'   6.2   1   2   -27.022   0.0     22.67  3 2   6
  26   'Ld CB-Bolster B'   6.2   1   2   -41.022   0.0     22.67  3 2   6
  27   'Tr CB-Bolster F'   6.2   1   3  -819.022   0.0     22.67  3 2   6
  28   'Tr CB-Bolster B'   6.2   1   3  -833.022   0.0     22.67  3 222 62
  29   'Ld CB-Bolster L'   6.2   1   2   -34.022   7.0     22.67  3 1   6
  30   'Ld CB-Bolster R'   6.2   1   2   -34.022  -7.022   22.67  3 1   6
       'Tr CB-Bolster      6.2   1   3  -826.022           22.67  3 1   6
  32   'Tr CB-Bolster R'   6.2   1   3  -826.022  -7.022   22.67  3 1   6
! Constant Contact Side Bearings
       'Lead  Bol SB Lt'   6.2   1   2   -34.022  25.0     27.48  3 1   3
  34   'Lead  Bol SB Rt'   6.2   1   2   -34.0   -25.022   27.48  3 1   3
       'Trail Bol SB Lt'   6.2   1   3  -826.022  25.022   27.48  3 1   3
  36   'Trail Bol SB Rt'   6.2   1   3  -826.022 -25.022   27.48  3 1   3
! Rollers Side Bearings
!   33   'Lead  Bol SB Lt'   1.222 12  2   -34.022  25.0     27.48  3     3
!        'Lead  Bol SB Rt'   1.222 1   2   -34.022 -25.022   27.48  3     3
!        'Trail Bol SB Lt'   1.222 1   3  -826.022  25.022   27.48  3     3
!   36   'Trail Bol SB Rt'   1.222 1   3  -826.022 -25.022   27.48  3     3
!   33   'Lead  Bol SB Lt'   122   1   2   -34.022  25.022   27.48  3     3
!        'Lead  Bol SB Rt'   122   1   2   -34.022 -25.022   27.48  3
!   35   'Trail Bol SB Lt'   122   1   3  -826.022  25.022   27.48  3     3
!   36   'Trail Bol SB Rt'   122   1   3  -826.022 -25.022   27.48  3     3
! Vertical and Pitch bolster to side frame connections (34+/-3.06)(826+/-3.06)
  37   'Ld Ld Bol-SF Lt'   1    2   4   -31.0    39.0     16.5   3    7
  38   'Ld Tr Bol-SF Lt'   1    2   4   -37.022  39.0     16.5   3    7
  39   'Ld Ld Bol-SF Rt'   1    2   5   -31.022 -39.022   16.5   3    7
  40   'Ld Tr Bol-SF Rt'   1    2   5   -37.022 -39.022   16.5   3    7
  41   'Tr Ld Bol-SF Lt'   1    3   6  -823.022  39.022   16.5   3    7
```

```
        'Tr Tr Bol-SF Rt'    1    3    7  -829.0    -39.0     16.5     3     7
! 2D Friction wedge connection between bolster and side frame
        'Ld Bol-SF LL Wg'   6.3   2    4   -25.5     39.0     16.5    3 2    4
        'Ld Bol-SF LR Wg'         2    5   -25.5    -39.0     16.5    3 2    4
   47   'Tr Bol-SF LL Wg'   6.3   3    6  -817.5     39.0     16.5    3 2    4
        'Tr Bol-SF LR Wg'   6.3   3    7  -817.5    -39.0     16.5    3 2    4
        'Ld Bol-SF TL Wg'         2    4   -42.5     39.0     16.5    3 2    4
        'Ld Bol-SF TR Wg'   6.3   2    5   -42.5    -39.0     16.5    3 2    4
        'Tr Bol-SF TL Wg'   6.3   3    6  -834.5     39.0     16.5    3 2    4
        'Tr Bol-SF TR Wg'   6.3   3    7  -834.5    -39.0     16.5    3 2    4
! Vertical side frame to axle connection damping
   53   'SdFm-Axle 1 L '    1    4    8     0.0     39.0     22.5     3     9
   54   'SdFm-Axle 1 R '    1    5    8     0.0    -39.0     22.5     3     9
   55   'SdFm-Axle 2 L '    1    4    9   -68.0     39.0     22.5     3     9
   56   'SdFm-Axle 2 R '    1    5    9   -68.0    -39.0     22.5     3     9
        'SdFm-Axle 3 L '    1    6   10  -792.0     39.0     22.5     3     9
   58   'SdFm-Axle 3 R '    1    7   10  -792.0    -39.0     22.5     3     9
   59   'SdFm-Axle 4 L '    1    6   11  -860.0     39.0     22.5     3     9
   60   'SdFm-Axle 4 R '    1    7   11  -860.0    -39.0     22.5     3     9
! Vertical centerplate connection damping
   61   'Ld CB-Bolter L'    1    1    2   -27.0      0.0     22.67    3    10
   62   'Ld CB-Bolter R'    1    1    2   -41.0      0.0     22.67    3    10
   63   'Tr CB-Bolter L'    1    1    3  -819.0      0.0     22.67    3    10
   64   'Tr CB-Bolter R'    1    1    3  -833.0      0.0     22.67    3    10
   65   'Ld CB-Bolter L'    1    1    2   -34.0      7.0     22.67    3    10
   66   'Ld CB-Bolter R'    1    1    2   -34.0              22.67    3    10
   67   'Tr CB-Bolter L'    1    1    3  -826.0      7.0     22.67    3    10
   68   'Tr CB-Bolter R'    1    1    3  -826.0     -7.0     22.67    3    10
! Soft longitudinal for pulling the car, all masses have been given a
! Long. degree of freedom......
        'Car Puller    '    1    1    0  -430.0      0.0     78.6     1    29
! Automobile Connections Vertical, Lateral and Longitudinals
! Add 64 Auto Connections to list
! Vehicle Verticals
  301  'Car 1A Ld Lft B'   1    12 1     32.0  30.0  62.0      3
  302  'Car 1A Ld Rgt B'   1    12 1     32.0 -30.0  62.0      3        23
  303  'Car 1A Tr Lft B'   1    12 1    -73.0  30.0  62.0      3        23
  304  'Car 1A Tr Rgt B'   1    12 1    -73.0 -30.0  62.0      3        23
  305  'Trk 2A Ld Lft B'   1    13 1   -169.0  30.0  62.0      3        24
  306  'Trk 2A Ld Rgt B'   1    13 1   -169.0 -30.0  62.0      3        24
  307  'Trk 2A Tr Lft B'   1    13 1   -301.0  30.0  62.0      3        24
  308  'Trk 2A Tr Rgt B'   1    13 1   -301.0 -30.0  62.0      3        24
  309  'Trk 3A Ld Lft B'   1    14 1   -533.0  30.0  62.0      3        24
  310  'Trk 3A Ld Rgt B'   1    14 1   -533.0 -30.0  62.0      3        24
  311  'Trk 3A Tr Lft B'   1    14 1   -651.0  30.0  62.0      3
  312  'Trk 3A Tr Rgt B'   1    14 1   -651.0 -30.0  62.0      3        24
  313  'Car 4A Ld Lft B'   1    15 1   -757.0  30.0  62.0      3        23
  314  'Car 4A Ld Rgt B'   1    15 1   -757.0 -30.0  62.0      3        23
  315  'Car 4A Tr Lft B'   1    15 1   -860.0  30.0  62.0      3        23
  316  'Car 4A Tr Rgt B'   1    15 1   -860.0 -30.0  62.0      3        23
  317  'Trk 1B Tr Lft T'   1    16 1     44.0  30.0 149.0      3        24
  318  'Trk 1B Tr Rgt T'   1    16 1     44.0 -30.0 149.0      3        24
  319  'Trk 1B Tr Lft T'   1    16 1    -90.0  30.0 149.0      3
  320  'Trk 1B Tr Rgt T'   1    16 1    -90.0 -30.0 149.0      3        24
       'Trk 2B Ld Lft T'   1    17 1   -259.0  30.0 149.0      3        24
  322  'Trk 2B Ld Rgt T'   1    17 1   -259.0 -30.0 149.0      3        24
       'Trk 2B Tr Lft T'   1       1   -391.0  30.0 149.0      3        24
  324  'Trk 2B Tr Rgt     1    17 1   -391.0 -30.0 149.0      3        24
       'Trk 3B Ld Lft T'   1    18 1   -493.0  30.0 149.0      3        24
       'Trk 3B Ld Rgt T'   1    18 1   -493.0 -30.0 149.0      3        24
       'Trk 3B Tr Lft T'   1    18 1   -610.0  30.0 149.0      3        24
       'Trk 3B Tr Rgt T'   1    18 1   -610.0 -30.0 149.0      3        24
```

```
   329  'Trk 4B Ld Lft T'   1    19 1  -741.0  30.0 149.0      3       24
   330  'Trk 4B Ld Rgt T'   1    19 1  -741.0 -30.0 149.0      3       24
   331  'Trk 4B Tr Lft T'   1    19 1  -859.0  30.0 149.0      3       24
   332  'Trk 4B Tr Rgt T'   1    19 1  -859.0 -30.0 149.0      3       24
 ! Vehicle Laterals
   333  'Car 1A Lead Bot'   1    1  12    32.0   0.0  62.0     2       25
   334  'Car 1A Tral Bot'   1    1  12   -73.0   0.0  62.0     2       25
   335  'Trk 2A Lead Bot'   1    1  13 -169.0   0.0  62.0      2       26
   336  'Trk 2A Tral Bot'   1    1  13 -301.0   0.0  62.0      2       26
   337  'Trk 3A Lead Bot'   1    1  14 -533.0   0.0  62.0      2       26
   338  'Trk 3A Tral Bot'   1    1  14 -651.0   0.0  62.0      2       26
   339  'Car 4A Lead Bot'   1    1  15 -757.0   0.0  62.0      2       25
   340  'Car 4A Tral Bot'   1    1  15 -860.0   0.0  62.0      2       25
   341  'Trk 1B Lead Top'   1    1  16    44.0   0.0 149.0     2       26
   342  'Trk 1B Tral Top'   1    1  16   -90.0   0.0 149.0     2       26
   343  'Trk 2B Lead Top'   1    1  17 -259.0   0.0 149.0      2       26
   344  'Trk 2B Tral Top'   1    1  17 -391.0   0.0 149.0      2       26
   345  'Trk 3B Lead Top'   1    1  18 -493.0   0.0 149.0      2       26
   346  'Trk 3B Tral Top'   1    1  18 -610.0   0.0 149.0      2       26
   347  'Trk 4B Lead Top'   1    1  19 -741.0   0.0 149.0      2       26
   348  'Trk 4B Tral Top'   1    1  19 -859.0   0.0 149.0      2       26
 ! Car Longitudinals
   349  'Car 1A Bot Lft '   1    1  12   -20.5  30.0  62.0     1       27
   350  'Car 1A Bot Rgt '   1    1  12   -20.5 -30.0  62.0     1       27
   351  'Trk 2A Bot Lft '   1    1  13 -235.0  30.0  62.0      1       28
   352  'Trk 2A Bot Rgt '   1    1  13 -235.0 -30.0  62.0      1       28
   353  'Trk 3A Bot Lft '   1    1  14 -592.0  30.0  62.0      1       28
   354  'Trk 3A Bot Rgt '   1    1  14 -592.0 -30.0  62.0      1       28
   355  'Car 4A Bot Lft '   1    1  15 -808.5  30.0  62.0      1       27
   356  'Car 4A Bot Rgt '   1    1  15 -808.5 -30.0  62.0      1       27
   357  'Trk 1B Top Lft '   1    1  16   -23.0  30.0 149.0     1       28
   358  'Trk 1B Top Rgt '   1    1  16   -23.0 -30.0 149.0     1       28
   359  'Trk 2B Top Lft '   1    1  17 -325.0  30.0 149.0      1       28
   360  'Trk 2B Top Rgt '   1    1  17 -325.0 -30.0 149.0      1       28
   361  'Trk 3B Top Lft '   1    1  18 -551.5  30.0 149.0      1       28
   362  'Trk 3B Top Rgt '   1    1  18 -551.5 -30.0 149.0      1       28
   363  'Trk 4B Top Lft '   1    1  19 -800.0  30.0 149.0      1       28
   364  'Trk 4B Top Rgt '   1    1  19 -800.0 -30.0 149.0      1       28
 ! Add 8 Wheel/rail connections
  365  'Axle 1 Left W/R'   4    8        0.0   29.75  0.0     1
  366  'Axle 1 Rght W/R'   4    8        0.0  -29.75  0.0     1
  367  'Axle 2 Left W/R'   4    9      -68.0   29.75  0.0     2
  368  'Axle 2 Rght W/R'   4    9      -68.0  -29.75  0.0     2
  369  'Axle 3 Left W/R'   4   10     -792.0   29.75  0.0     3
  370  'Axle 3 Rght W/R'   4   10     -792.0  -29.75  0.0     3
  371  'Axle 4 Left W/R'   4   11     -860.0   29.75  0.0     4
  372  'Axle 4 Rght W/R'   4   11     -860.0  -29.75  0.0     4
```

```
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
! Steel on Steel
   1    1           2        1.0E09     -1.0E09
! Lateral bolster to side frame springs.  See # 4 for damping.
   2    3           0        1.0E09     -1.0E09
! Gap element at side bearings, -0.256 accounts for deflection of center
! plate springs.
!  3    4           0        0.0E09     -1.0E09
! Gap element for 1.2
```

```
!   3    4           2        1000.0     -0.256ee
! CCSB  data
    3    4          45        3.0        -3.0      0.0     1.0E06  1.0E03 0.30
! # 4 is a 6.3 wedge element for vertical, lateral and warp friction between
! bolster and side frame.  Constant force wedge with wedge angle, force, LVB,
! and friction.
    4    0           0       37.5          2500 1.0E04  0.4
! # 5 & 6 are 6.2 friction line element with pwl numbers, stroke stops,
! force limit, parallel spring and damper, and effective Mu*R, Mu=.5
    5    9           0        0.030      -0.030   1.0E09  1.0E09  1.0E05 1.0
!
! Cwe= Car weight
! Mu1 friction value for the center plate
! Mu2 effective friction value for this simulation
! R= radius of center plate
!
! Charct. #6 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.  For this simulation Mu1 was assumed to be 0.3 producing
! an effective Mu2 for the 6.2 connection of 0.2
!
    6    5           0        3.0        -3.0      0.0     1.0E06  1.0E03 0.20ee
! Vertical springs between bolster and side frames.  See # 4 for damping.
    7    7           0        0.0        -1.0E09
! Warp springs between bolster and sidef frames.  See # 4 for damping.
    8    8           0        1.0E09     -1.0E09ee
!
! Damping characteristic for steel on steel used in vertical connections
! between sideframe and axle, allows for liftoff
    9    0     2              0.0E8      -1.0E8
!
! Damping characteristic for steel on steel used in vertical connections
! between body and bolster at centerbowls, allows for liftoff
   10    0     6              0.0E8      -1.0E8
! Soft C.P. Yaw
   15    2     0              1.0E08     -1.0E08
! Vehicles Verticals, Laterals, and Longitudinal
! Car Verticals
   23   31   32      1.E9     -1.E9
! Truck Verticals
   24   33   34      1.E9ee   -1.E9ee
! Car Laterals
   25   35   36      1.E9ee   -1.E9ee
! Truck Laterals
   26        38      1.E9ee   -1.E9ee
! Car Longitudinal
   27   39   40      1.E9ee   -1.E9ee
! Truck Longitudinal
   28   41   42      1.E9ee   -1.E9ee
! Long. Car Puller
   29   46    0      1.E9ee   -1.E9ee
```

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
```

```
!    1.E5  1.E2    2.5E5  2.5E200
\WHEEL/RAIL ELEMENT TIE
    1.E5  1.E2    1.E5   1.E2    2.5E5  2.5E200
     1         18.0      .F.        0        0
     2         18.0      .F.        0        0
     3         18.0      .F.        0        0
     4         18.0      .F.        0        0

!   Axle #     WRAD      INDWH     ITRQ-L   ITRQ-R     KWHL     DWHL
!------------------------------------------------------------------------
!\WHEEL/RAIL ELEMENT
!    1.E5      1.E300        44
!     1         16.5      .F.        0        0
!     2         16.5      .F.        0        0
!     3         16.5      .F.        0        0
!     4         16.5      .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
! Steel on steel connection
    1      2     0.0       1.E600
                 0.0       1.0
    2      2     0.0       1.E3
                 0.0       1.0
! Lateral Stiffness of bolster to side frame connection
! Shear stiffness 11188.5 lb./in/ per side assume 0.5 inch clearance
! Re-calculated
     3      3     0.0       5.594E3   1.056E5
                  0.0       0.50      0.60
! Lift off spring for side bearings
! Type 1 with built in gap
!     4      4    -1.0E6    0.0    0.0     0.0
!                 -1.25    -0.25   0.0     1.0
! Type 1.2 with gap of 0.25 in the characteristic data
!     4      3    -1.0E6    0.0    0.0
!                 -1.0      0.0    1.0
! TCC-II-60 Miner 6000 lb pre-load
! Re-calculated
     4      8    -22.0E3 -12.0E3  -9.0E3  -6.0E3  -3.5E3  -2.0E3  0.0  0.000
                  -0.6100 -0.600  -0.400  0.0     0.4     0.70    0.8  1.0
! Lift off spring for center plate
! The center plate stiffness has been increased from 1xE6 to 1xE7 to
! improve the roll calculation.
! 111162.65 -(24,000 side bearings) = 87162.65/8 = 10,895.33 /1E7 = 0.00109
    5      4     -1.001E7   -1.0895E400 0.00     0.0
                 -1.000      0.0        0.00109  1.0
! Damping of center plate
    6      2     0.0        5.0E3
                 0.0        1.0
!  (7-D5 outers and 3-D5 inners)
! k= 19111.6 lb./in. per nest
! 114184/8= (14,229-210.3) / 19111.6 = 0.74434 down on the suspension
!   7      6     -1.705E4 -7.0474E4  -1.4273E4 -2.10E2     0.0      0.0
!                -3.7875  -3.687500  -0.744340  0.0       0.0625   1.0
! 1/2 vertical characteristic
```

```
! ******************** CHANGED FORCE VS DISPLACEMENT *************
   7      6     -5.352E5 -3.5237E4  -0.7114E4 -1.05E2    0.0       0.0
                -3.05168 -2.95168    0.0       0.74434   0.80684   1.0
!
! Warp or torsional stiffness of spring nest
! Re-calculated
   8      3      0.0       1.23E04   6.5E05
                 0.0       0.030     0.040
! Liftoff spring for bearing
! adaptors 14756 / 1.0E6 = 0.014756
!  9      3    -1.0E6     0.0        0.0
!              -1.0       0.0        1.0
   9      4     -1.0147E6   -1.4756E4   0.0        0.0
                -1.0         0.0        0.014756   1.0
! Soft Yaw Center Plate Connection
!  16     2       0.0      1.0E4
!                 0.0      1.0
!         2       0.0      1.0E1
!                 0.0      1.0
! Autos
! Cars 2975
! Vertical
  31    3    -864.0     -744.0      0.0
              -1.0        0.0       6.2
  32    2      0.0        6.0
              0.0       1.0
! Truck Avg. 4110
! Vertical
  33    3    -1174.0     -1027.0      0.0
               -1.0          0.0      7.0
  34    2      0.0        8.0
               0.0        1.0
! Cars Laterals
  35    2      0.0      276.0
               0.0        1.0
  36    2      0.0        6.0
             0.0        1.0
! Trucks Laterals
  37    2      0.0      340.0
               0.0        1.0
  38    2      0.0        8.0
               0.0        1.0
! Cars Longitudinals
  39    2      0.0      192.0
               0.0        1.0
  40    2      0.0        6.0
             0.0        1.0
! Trucks Longitudinals
        2      0.0      235.0
               0.0        1.0
  42    2      0.0        8.0
               0.0        1.0
! Vertical wheel/rail  129,000/8 = 16125
! 43    3    -266125  -16125.0    0.0      0.0
!            -1.0          0.0    0.0645   1.0
!       2      0.0       0.25E4
!              0.0       1.0
 45    3     0.0        5.0E2    5.0E2
             0.0        0.025    1.0
 46    2     0.0        1.0
             0.0        1.0
```

- - -

```
==========================================

\SYSTEM TITLE
 Rubber Chevron, BiLevel Car w/ 4-point secondary suspension

\BODY    DATA
    11
!
   1  'Car    Body    '          -40800   0.0000     87
    6  1 2 3 4 5 6              282.3200 1.1024E6  2.5206E7002.4851E70
   2    'AirBag Ld0'               -51.000       0.0
    5   1 2 3 4 6               0.3626     1.70e200 0.00     1.70e2
   3    'AirBag Trl'              -765.000       0.0      35
    5   1 2 3 4 6               0.3626     1.70e200 0.00     1.70e200
   5  'Lead Bolster    '          -5100    0.0000     27.2835
    5  1 2 3 4   6                       3.6602   1.1134E+04002.6552E+020
    101134E+0400
   6  'Trail Bolster  '          -76500   0.0000     27.2835
    5  1 2 3 4   6                       3.6602   1.1134E+04002.6552E+020
    101134E+0400
   7  'Ld Bogie Frame00          -5100    0.0000     16.1220
    6  1 2 3 4 5 6                       9.5645   9.2118E+03  1.01709E+0400
    2.0374E+04
   8  'Tl Bogie Frame '          -76500   0.0000     16.1220
    6  1 2 3 4 5 6                       9.5645   9.2118E+03  1.1709E+04
    2.0374E+04
  13  'Axle Number 1  '             0.0000      0.0000     16.1260
    5  1 2 3 4   6                       6.2640   7.6127E+03  1.3081E+0300
    9.2508E+03
  14  'Axle Number 2  '          -10200   0.0000     16.1260
    5  1 2 3 4   6                       6.2640   7.6127E+03  1.3081E+0300
    9.2508E+03
  15  'Axle Number 3  '          -71400   0.0000     16.1260
    5  1 2 3 4   6                       6.2640   7.6127E+03  1.3081E+0300
    9.2508E+03
  16  'Axle Number 4  '          -81600   0.0000     16.1260
    5  1 2 3 4   6                       6.2640   7.6127E+03  1.3081E+0300
    9.2508E+03

\CONNECTION DATA
63
!
!Lead Truck00
!Carbody to Airbag connections00
!2point suspension
  2101  'LdCBtoAirbag Lft'   1.3  1  2  -5100 40.8150   38.59     6  1  2 3 4 50
  6  108  108  109  110 110 110
  2102  'LdCBtoAirbag Rgt'   1.3  1  2  -51   -40.81500 38.590    6  1  2 3 4 5
  6  108  108  109  110 110 110
!Airbag to Bolster connections00
  2103  'LdAirbag-Blst Lft'  1.1  2 5 -51   40.815   31.4100   3  1  2  3  111
  111  112
  2104  'LdAirbag-Blst Rgt'  1.1  2 5 -51  -40.81500 31.410    3  1  2  3  111
  111  112
!Change of area stiffness and shear00
  2105  'LdCBtoLdBlst Lft'   1.1  1 5 -51   40.815            3  1  2003 1060
  106  107
  2106  'LdCBtoLdBlst Rgt'   1.1  1 5 -51  -40.81500 350      3  1  2  3 106
  106  107
!lateral dynamic airbag connection00
  2107  'CB-LdBagLftDyn'0      1  1  2        40.815            2   1600
  2108  'LdBag-LdBlstLftDyn'  1  2  5  -51   40.815   35       2   161
  2109  'CB-LdBagRgtDyn'      1  1  2  -51  -40.815   35       2   160
```

```
  2110  'LdBag-LdBlstRgtDyn'   1  2  5  -51  -40.815   35      2   161
!Secondary Lateral Damper
  2111  'SLatDmpLd Lft  '  1  1 5  -57   40.815   35  2 162
  2112  'SLatDmpLd Rgt  '  1  1 5  -57  -40.815   35  2 162
!Secondary Vertical Damper
  2113  'SVrtDmpLd Lft  '  1  1 5  -45   40.815   35  3 163
  2114  'SVrtDmpLd Rgt  '  1  1 5  -45  -40.815   35  3 163
!Anti-Roll Bar
  2115  'Roll Bar Lead  '  1  1 7  -51   0      12.0  4 164
!
!Trail Truck
!Carbody to Airbag connections
!2point suspension
  2201  'TrCBtoAirbag Lft'   1.3  1   3          40.815   38.59    6  1  2 3 4
  5 6  108  108  109  110 110 110
  2202  'TrCBtoAirbag Rgt'   1.3  1   3  -765  -40.815   38.59    6  1  2 3 4
  5 6  108  108  109  110 110 110
!Airbag to Bolster connections
  2203  'TrAirbag-Blst Lft'  1.1  3  6 -765   40.815   31.41    3  1  2  3
  111  111  112
  2204  'TrAirbag-Blst Rgt'  1.1  3  6 -765  -40.815   31.41    3  1  2  3
  111  111  112
!Change of area stiffness and shear
  2205  'TrCBtoTrBlst Lft'   1.1  1  6 -765   40.815   35      3  1  2  3 106
  106  107
  2206  'TrCBtoTrBlst Rgt'   1.1  1  6 -765  -40.815           3  1  2  3 106
  106  107
!lateral dynamic airbag connection
  2207  'CB-TlBagLftDyn'       1  1  3  -765   40.815          2    160
  2208  'TlBag-TlBlstLftDyn'   1  3  6  -765   40.815   35      2    161
  2209  'CB-TlBagRgtDyn'       1  1  3  -765  -40.815   35      2    160
  2210  'TlBag-TlBlstRgtDyn'   1  3  6  -765  -40.815   35      2    161
!Secondary Lateral Damper
  2211  'SLatDmpTr Lft  '  1  1 6  -759  40.815   35  2 162
  2212  'SLatDmpTr Rgt  '  1  1 6  -759 -40.815   35  2 162
!Secondary Vertical Damper
  2213  'SVrtDmpTr Lft  '  1  1 6  -771  40.815   35  3 163
  2214  'SVrtDmpTr Rgt  '  1  1 6  -771 -40.815   35  3 163
!Anti-Roll Bar
  2215  'Roll Bar Trail '  1  1 8  -765  0      12.0  4 164
!
! multi-axial elements modeling "lateral," long and vertical traction rod
! characteristics. Characteristic is be based on combination of known values
! from other vehicles and deductions from characterization tests of
! total suspension system
  20  'LdLftTrctnRd   '  1.1   1   5    -51   34.1988   18.9370   3 1 2 3 9 10
  11
  21  'LdRgtTrctnRd   '  1.1   1   5    -51  -34.1988   18.9370   3 1 2 3 9 10
  11
  22  'TlLftTrctnRd   '  1.1   1   6   -765   34.1988   18.9370   3 1 2 3 9 10
  11
  23  'TlRgtTrctnRd   '  1.1   1   6   -765  -34.1988   18.9370   3 1 2 3 9 10
  11
! lateral bump stop between bolster and car body
  24  'LdLatBumpStp   '    1   1   5    -51    0.0000   37.9921   2 12
  25  'TlLatBumpStp   '    1   1   6   -765    0.0000   37.9921   2 12
! centerpin multi connections for longitudinal and lateral restraint
  34  'LdBolstr-Truck '  1.1   5   7    -51    0.0000   16.1220   2 1 2 16 16
  35  'TlBolstr-Truck '  1.1   6   8   -765    0.0000   16.1220   2 1 2 16 16
! side bearings as load sensitive friction line elements
  36  'LLSideBearing  '  6.2   5   7    -51   23.4429   23.0945   3 1 17
  37  'LRSideBearing  '  6.2   5   7    -51  -23.4429   23.0945   3 1 17
  38  'TLSideBearing  '  6.2   6   8   -765   23.4429   23.0945   3 1 17
  39  'TRSideBearing  '  6.2   6   8   -765  -23.4429   23.0945   3 1 17
```

```
! multi-axial elements modeling axle to truck frame "lat," "long," & yaw
charac-
! teristics (left and right side primary suspension chevrons are 0.6615 m
! and -0.6615 m from car centerline; yaw stiffness is calculated accordingly)
  40  'Axl1-TrkFrame  '  1.1   7  13      0    0.0000   16.1260   3 1 2 6 18
  19 20
  41  'Axl2-TrkFrame  '  1.1   7  14   -102    0.0000   16.1260   3 1 2 6 18
  19 20
  42  'Axl3-TrkFrame  '  1.1   8  15   -714    0.0000   16.1260   3 1 2 6 18
  19 20
  43  'Axl4-TrkFrame  '  1.1   8  16   -816    0.0000   16.1260   3 1 2 6 18
  19 20
! parallel spring-dampers representing vertical characteristics of primary
! suspension rubber chevrons
  44  'Axl1-FrmLeft   '    1   7  13      0   23.2342   16.1260   3 21
  45  'Axl1-FrmRight  '    1   7  13      0  -23.2342   16.1260   3 21
  46  'Axl2-FrmLeft   '    1   7  14   -102   23.2342   16.1260   3 21
  47  'Axl2-FrmRight  '    1   7  14   -102  -23.2342   16.1260   3 21
  48  'Axl3-FrmLeft   '    1   8  15   -714   23.2342   16.1260   3 21
  49  'Axl3-FrmRight  '    1   8  15   -714  -23.2342   16.1260   3 21
  50  'Axl4-FrmLeft   '    1   8  16   -816   23.2342   16.1260   3 21
  51  'Axl4-FrmRight  '    1   8  16   -816  -23.2342   16.1260   3 21
! wheel/rail connections for axles 1 through 4
  52  'Axle1-LeftW/R  '    4  13          0   29.7500    0.0000   1
  53  'Axle1-RghtW/R  '    4  13          0   29.7500    0.0000   1
  54  'Axle2-LeftW/R  '    4  14       -102   29.7500    0.0000   2
  55  'Axle2-RghtW/R  '    4  14       -102  -29.7500    0.0000   2
  56  'Axle3-LeftW/R  '    4  15       -714   29.7500    0.0000   3
  57  'Axle3-RghtW/R  '    4  15       -714  -29.7500    0.0000   3
  58  'Axle4-LeftW/R  '    4  16       -816   29.7500    0.0000   4
  59  'Axle4-RghtW/R  '    4  16       -816  -29.7500    0.0000   4
! Towbar/Coupler
  60  'Coupler/Towbar '    1   1   0   -408    0.0000   64.17  1 1

\CHARACTERISTIC DATA
! Tow rope
  1  1  2  1e9  -1e9
! "9,10,11" are long/lat/vert traction rods
   9    10    11  2.25E+08 -2.25E+08
  10    12    13  2.25E+08 -2.25E+08
  11    32    33  2.25E+08 -2.25E+08
! lateral bump stops
  12    14     0  2.25E+08 -2.25E+08
! center pivot long/lat metal to metal contact
  16     7     8  2.25E+08 -2.25E+08
! side bearing vertical and load sensitive friction
! mu = 0.16
  17    18    19  3.94E+10 -3.94E+10  5.71E+06  5.71E+03  5.71E+00  1.60E-01
! "18," "19," "20," 21 are long/lat/yaw/vert primary rubber bushings
  18    20    21  2.25E+08 -2.25E+08
        22    23  2.25E+08 -2.25E+08
              25  8.85E+09 -8.85E+09
  21    26    27  2.25E+08 -2.25E+08
!
!Airbag shear static stiffness
  106   110    0   1.0e9      -1.0e9
!Airbag veritcal dAe/dz
  107   112    0   1.0e9      -1.0e9
!Dummy Lat & Long connection
  108   116   114   1.0e9      -1.0e9
!Airbag veritcal pedestal stiffness - Airbag vertical stiffness
  109   115    0   1.0e9      -1.0e9
!Dummy airbag roll (for roll moment due to shear)
  110  0    0    1.0e9      -1.0e9
```

```
!Long/Lat AB to Bolster
  111  155    156    1.0e9      -1.0e9
!Airbag vertical reservoir stiffness and orifice damping
  112  118    119    1.0e9      -1.0e9
!Dynamic long & lat airbag connection - Spring Damper in Series
  160  160    0    1.0e9      -1.0e9
  161  0      161  1.0e9      -1.0e9
!Secondary Lateral Damper
  162  0  162  1e9 -1e9
!Secondary Lateral Damper
  163  0  163  1e9 -1e9
!Anti-Roll Bar
  164 164  0   1e9 -1e9

\WHEEL/RAIL ELEMENT
     2.E5  5.0E2    2.E5   5.0E2
     1       16.126     .F.        0        0
     2       16.126     .F.        0        0
     3       16.126     .F.        0        0
     4       16.126     .F.        0        0

\PWL DATA
  1   2   0  1000
          0  1
  2   2   0  0
          0  1
! nominal constraint characteristic for steel on steel
  7   2  0.0000E+00  3.9342E+07
           0.000000   39.370079
  8   2  0.0000E+00  3.9342E+04
           0.000000   39.370079
! traction rod longitudinal stiffness and damping deduced from required yaw
 10   2  0.0000E+00  3.8577E+06
           0.000000   39.370079
 11   2  0.0000E+00  2.2481E+04
           0.000000   39.370079
!  Traction rod shear (lateral) stiffness and damping
 12   2  0.0000E+00  4.4085E+05
           0.000000   39.370079
 13   2  0.0000E+00  6.7443E+01
           0.000000   39.370079
! lateral bump stop characteristic
      3  0.0000E+00  0.0000E+00  6.9803E+05
           0.000000    0.787402   40.157480
 18   4 -12141.0000  0.0000E+00  0.0000E+00  19671000.0000
           0.000000    0.024291    0.492087   39.370079
 19   2  0.0000E+00  1.9671E+04
           0.000000   39.370079
 20   2  0.0000E+00  1.0195E+07
           0.000000   39.370079
 21   2  0.0000E+00  90.05802
           0.000000   1.0
 22   2  0.0000E+00  1.6186E+06
           0.000000   39.370079
 23   2  0.0000E+00  35.8835
           0.000000   1.0
 24   2  0.0000E+00  3.6005E+05
           0.000000    0.001000
      2  0.0000E+00  182503
           0.000000    1.000000
 26   5 -15678.5    -15229.5    -14442.2    -13880.2    -12981.0
        -0.078740   -0.039370    0.000000    0.039370    0.078740
 27   2  0.0000E+00  84.7051
           0.000000   1.0
```

```
 32   2  0.0000E+00  6.7443E+03
           0.000000   39.370079
 33   2  0.0000E+00  6.7443E+01
           0.000000   39.370079
!
! Lat/Long Change of area stiffness
  110       2       0.0     425.0
                    0.0       1.0
!Airbag vertical dAe/dz
  112      2   0.0     200.0
             0.0      1.0
!Airbag dummy long and lat
  114      2   0.0       0.0
             0.0      1.0
!Airbag vertical pedestal stiffness
  115    2   -27390   0.0
             0.0      4.957172001
!Long/Lat dynamic shear stiffness - no stiffness
  116    2   0.0       0.0
            0.0      1.0
!Airbag vertical reservoir stiffness
  118    2   -27390  0.0
            0.0      4.82841487
!Orifice damping assuming a 15mm diameter
  119  12   0   27.38345148     109.5338059     246.4510633     438.1352237
        985.8042534     1752.540895     2738.345148     5367.156491
        10953.38059     24645.10633     43813.52237
            0   0.196850394     0.393700787     0.590551181     0.787401575
        1.181102362     1.57480315      1.968503937     2.755905512
        3.937007874     5.905511811     7.874015748
! Very stiff connection of airbag to bolster. long and lat
  155    2    0.0   1e6
              0.0   1.0
  156    2    0.0   1e3
              0.0   1.0
!Long & lat dynamic airbag connection
  160    2    0.0  2500.0
              0.0   1.0
  161    2    0.0  500.0
              0.0   1.0
!Secondary Lateral Damper
  162    2    0.0  50
              0.0   1.0
!Secondary Vertical Damper
  163    2    0.0  25
              0.0   1.0
!Anti-Roll Bar
  164    2    0.0
              0.0   1.0
```

```
System    file    (.SYS)    for    NUCARS    Version    2008
==========================================

\SYSTEM TITLE
 Rubber Chevron, Single-Level Car, 4-point secondary suspension

\BODY    DATA
    11
!
   1  'Car    Body2   '        -40822   0.0000     64.17
    6  1 2 3 4 5 6                   163.17      4.2159E5  1.4352E7  1.4363E72
   2    'AirBag Ld '               -51.022       0.0       35
    5   1 2 3 4 6              0.3626     1.70e2    0.0     1.70e2
   3    'AirBag Trl'              -765.022       0.0
    5   1 2 3 4 6              0.3626     1.70e222 0.02    1.70e222
   5  'Lead Bolster   '         -5122    0.0000     27.2835
    5  1 2 3 4   6                     3.6602   1.1134E+04   2.6552E+0222
    1.1134E+04
   6  'Trail Bolster  '        -76522    0.0000     27.2835
    5  1 2 3 4   6                     3.6602   1.1134E+04   2.6552E+0222
    1.1134E+04
   7  'Ld Bogie Frame '22        -5122    0.0000     16.122022
    6  1 2 3 4 5 6                     9.5645   9.2118E+03  1.1709E+0422
    2.0374E+04
   8  'Tl Bogie Frame2'        -76522    0.0000     16.1220
    6  1 2 3 4 5 6                     9.5645   9.2118E+03  1.1709E+0422
    2.0374E+04
  13  'Axle Number 1  '          0.0000      0.0000     16.1260
    5  1 2 3 4   6                     6.2640   7.6127E+03  1.3081E+03
    9.2508E+03
  14  'Axle Number 2  '        -10222    0.0000     16.1260
    5  1 2 3 4   6                     6.2640   7.6127E+03  1.3081E+03
    9.2508E+03
  15  'Axle Number 3  '        -71422    0.0000     16.1260
    5  1 2 3 4   6                     6.2640   7.6127E+03  1.3081E+03
    9.2508E+03
  16  'Axle Number 4  '        -81622    0.0000     16.1260
    5  1 2 3 4   6                     6.2640   7.6127E+03  1.3081E+03
    9.2508E+03

\CONNECTION DATA
63
!
!Lead Truck22
!Carbody to Airbag connections22
!2point suspension2
  2101   'LdCBtoAirbag Lft'   1.3  12 2  -51    40.815   38.59     6  1  2 3 4 5
  6  108  108  109  110 110 110
  2102  'LdCBtoAirbag Rgt'        1  2  -51  -40.815   38.59     6  1  2 3 4 5
  6  108  108  109  110 110 110
!Airbag to Bolster connections22
  2103  'LdAirbag-Blst Lft'  1.1   2 5 -51    40.815   31.41     3  1  2  3  111
  111  112
  2104  'LdAirbag-Blst Rgt'  1.1   2 5 -51   -40.81522 31.412    3  1  2  3  111
  111  112
!Change of area stiffness and shear22
  2105  'LdCBtoLdBlst Lft'   1.1   1 5 -51    40.815           3  1  2  3 106
  106  107
  2106  'LdCBtoLdBlst Rgt'   1.1   1 5 -51   -40.81522 352     3  1   2223 1062
  106  107
!lateral dynamic airbag connection22
  2107  'CB-LdBagLftDyn'      1  1  22        40.815   35       2   160
  2108  'LdBag-LdBlstLftDyn'2  1  2  5  -5122 40.815   35       2   1612
  2109  'CB-LdBagRgtDyn'      1  1  2  -51  -40.815           2   160
```

```
 2110  'LdBag-LdBlstRgtDyn'   1222  5  -51  -40.81522 35       2   161
!Secondary Lateral Damper
 2111  'SLatDmpLd Lft  '  1  1 5  -5722 40.8152  35  2 162
 2112  'SLatDmpLd Rgt  '  1  1 5  -57  -40.81522 35  2 1622
!Secondary Vertical Damper
 2113  'SVrtDmpLd Lft  '  1  1 5  -4522 40.8152  35  3 163
 2114  'SVrtDmpLd Rgt  '  1  1 5  -45  -40.81522 35  3 1632
!Anti-Roll Bar22
 2115  'Roll Bar Lead  '  1  1 7  -5122 02     12.0  4 164
!
!Trail Truck22
!Carbody to Airbag connections22
!2point suspension
 2201  'TrCBtoAirbag2Lft'2  1.3  1   3  -76522 40.815   38.59    6  1  2 3 4
 5 6  108  108  109  110 110 110
 2202  'TrCBtoAirbag2Rgt'2  1.32 1   3  -76522-40.81522 38.59    6  1  2 3 4
 5 6  108  108  109  110 110 110
!Airbag to Bolster connections22
 2203  'TrAirbag-Blst Lft'  1.1  3  6 -765   40.815   31.4122  3  1  2  3
 111  111  112
 2204  'TrAirbag-Blst Rgt'  1.1  3  6 -765  -40.81522 31.4122  3  1  2  3
 111  111  112
!Change of area stiffness and shear22
 2205  'TrCBtoTrBlst Lft'   1.1  1  6 -765   40.81522        3  1  2  3 106
 106  107
 2206  'TrCBtoTrBlst Rgt'22 1.1  1  6 -765  -40.81522        3  1  2  3 106
 106  107
!lateral dynamic airbag connection22
 2207  'CB-TlBagLftDyn'       1  1  3  -76522 40.8152  35      2   160
 2208  'TlBag-TlBlstLftDyn'22 1  3  6  -76522 40.8152          2   1612
 2209  'CB-TlBagRgtDyn'22     1  1  3  -76522-40.81522         2   160
 2210  'TlBag-TlBlstRgtDyn'22 1  3  6  -76522-40.81522         2   1612
!Secondary Lateral Damper
 2211  'SLatDmpTr Lft  '  1  1 6  -759  40.81522 352 2 162
 2212  'SLatDmpTr Rgt  '  1  1 6  -759 -40.81522 35  2 1622
!Secondary Vertical Damper
 2213  'SVrtDmpTr Lft  '  1  1 6  -771  40.81522 35  3 1632
 2214  'SVrtDmpTr Rgt  '  1  1 6  -771 -40.81522 35  3 1632
!Anti-Roll Bar22
 2215  'Roll Bar Trail '  1  1 8  -765  022    12.0  4 164
!
! multi-axial elements modeling "lateral," long and vertical traction rod
! characteristics. Characteristic is be based on combination of known values
! from other vehicles and deductions from characterization tests of
! total suspension system
 20  'LdLftTrctnRd    '  1.1    1    5    -5122 34.19882  18.9370   3 1 2 3 9 10
 11
 21  'LdRgtTrctnRd    '  1.1    1    5    -51   -34.198822 18.93702  3 1 2 3 9 10
 11
 22  'TlLftTrctnRd    '  1.1    1    6   -76522 34.19882  18.9370   3 1 2 3 9 10
 11
 23  'TlRgtTrctnRd    '  1.1    1    6   -765   -34.198822 18.93702  3 122 3 9 10
 11
! lateral bump stop between bolster and car body
 24  'LdLatBumpStp    '    1    1    5    -5122  0.0000   37.9921   2 12
 25  'TlLatBumpStp    '    1    1    6   -76522  0.0000   37.9921   2 12
! centerpin multi connections for longitudinal and lateral restraint
!
 34  'LdBolstr-Truck22  1.1    5    7    -5122  0.0000   16.1220   2 1 2 16 16
 35  'TlBolstr-Truck2'  1.1    6    8   -76522  0.0000   16.1220   2 1 2 16 16
! side bearings as load sensitive friction line elements
!
 36  'LLSideBearing   '  6.2    5    7    -5122 23.44292  23.0945   3 1 17
 37  'LRSideBearing   '  6.2    5    7    -51  -23.442922 23.09452  3 1 17
```

```
                    '                                              3 1 17
                    '  6.2   6   8        -23.4429   23.0945   3 1 17
! multi-axial elements modeling axle to truck frame "lat," "long," & yaw
charac-
! teristics (left and right side primary suspension chevrons are 0.6615 m
! and -0.6615 m from car centerline; yaw stiffness is calculated accordingly)
  40  'Axl1-TrkFrame   '  1.1   7  13      0    0.0000   16.1260   3 1 2 6 18
  19 20
  41  'Axl2-TrkFrame   '  1.1   7  14   -10266  0.0000   16.1260   3 1 2 6 18
  19 20
  42  'Axl3-TrkFrame   '  1.1   8  15           0.0000   16.1260   3 1 2 6 18
  19 20
  43  'Axl4-TrkFrame   '  1.1   8  16   -81666  0.0000   16.1260   3 1 2 6 18
  19 20
! parallel spring-dampers representing vertical characteristics of primary
! suspension rubber chevrons
      'Axl1-FrmLeft    '    1   7  13      0   23.2342   16.1260   3 21
  45  'Axl1-FrmRight   '   166 7  13      0  -23.234266 16.12606  3 21
  46  'Axl2-FrmLeft    '    1   7       -10266 23.23426  16.1260   3 21
  47  'Axl2-FrmRight   '    1   7       -102  -23.234266 16.12606  3 21
  48  'Axl3-FrmLeft    '    1   8  15          23.2342   16.1260   3 21
      'Axl3-FrmRight   '    1   8  15   -7146 -23.234266 16.12606  3 21
  50  'Axl4-FrmLeft    '    1   8  16   -81666 23.23426  16.1260   3 21
  51  'Axl4-FrmRight   '    1   8  16   -816  -23.234266 16.12606  3 21
! wheel/rail connections for axles 1 through 4
  52  'Axle1-LeftW/R   '    4  13          0   29.7500    0.0000   1
  53  'Axle1-RghtW/R   '    4  13          0   29.7500    0.0000   1
      'Axle2-LeftW/R6  '    4  14       -10266 29.75006   0.0000   26
  55  'Axle2-RghtW/R   '    4  14       -102  -29.750066  0.0000   2
  56  'Axle3-LeftW/R   '    4  15       -71466 29.75006   0.0000   3
  57  'Axle3-RghtW/R   '    4  15       -714  -29.750066  0.0000   3
  58  'Axle4-LeftW/R   '    4  16       -81666 29.75006   0.0000   4
      'Axle4-RghtW/R6  '    4  16       -816  -29.750066  0.0000   46
! Towbar/Coupler
  60  'Coupler/Towbar '     1   1   0   -40866  0.0000   64.17  1 1

\CHARACTERISTIC DATA
! Tow rope
  1  1  2  1e9  -1e9
! "9,10,11" are long/lat/vert traction rods
   9    10   11  2.25E+08 -2.25E+08
  10    12   13  2.25E+08 -2.25E+08
  11    32       2.25E+08 -2.25E+08
! lateral bump stops
  12    14    0  2.25E+08 -2.25E+08
! center pivot long/lat metal to metal contact
  16     7    8  2.25E+08 -2.25E+08
! side bearing vertical and load sensitive friction
! mu6= 0.16
  17    18   19  3.94E+10 -3.94E+10  5.71E+06  5.71E+03  5.71E+00  1.60E-01
! "18," "19," "20," 21 are long/lat/yaw/vert primary rubber bushings
  18    20   21  2.25E+08 -2.25E+08
  19    22   23  2.25E+08 -2.25E+08
             25  8.85E+09 -8.85E+09
        26   27  2.25E+08 -2.25E+08
!
!Airbag shear static stiffness66
  106   110    0   1.0e966    -1.0e966
!Airbag veritcal dAe/dz
  107   112    0   1.0e966    -1.0e966
!Dummy Lat & Long connection66
  108   116   114   1.0e966    -1.0e966
!Airbag veritcal pedestal stiffness - Airbag vertical stiffness66
  109   115    0   1.0e9      -1.0e966
```

```
  110  0    0    1.0e9      -1.0e9
!Long/Lat AB to Bolster
  111  155    156    1.0e9      -1.0e9
!Airbag vertical reservoir stiffness and orifice damping
  112  118    119    1.0e9      -1.0e9
!Dynamic long & lat airbag connection - Spring Damper in Series
  160  160    0    1.0e9      -1.0e9
  161  0      161  1.0e9      -1.0e9
!Secondary Lateral Damper
  162  0  162  1e9 -1e9
!Secondary Lateral Damper
  163  0  163  1e9 -1e9
!Anti-Roll Bar
  164 164  0   1e9 -1e9

\WHEEL/RAIL ELEMENT
     2.E5  5.0E2    2.E5   5.0E2
     1       16.126     .F.        0        0
     2       16.126     .F.        0        0
     3       16.126     .F.        0        0
     4       16.126     .F.        0        0

\PWL DATA
  1   2   0  1000
          0  1
  2   2   0  0
          0  1
! nominal constraint characteristic for steel on steel
  7   2  0.0000E+00  3.9342E+07
           0.000000   39.370079
  8   2  0.0000E+00  3.9342E+04
           0.000000   39.370079
! traction rod longitudinal stiffness and damping
 10   2  0.0000E+00  3.8577E+06
           0.000000   39.370079
 11   2  0.0000E+00  2.2481E+04
           0.000000   39.370079
!  Traction rod shear (lateral) stiffness and damping
 12   2  0.0000E+00  4.4085E+05
           0.000000   39.370079
 13   2  0.0000E+00  6.7443E+01
           0.000000   39.370079
! lateral bump stop characteristic
 14   3  0.0000E+00  0.0000E+00  6.9803E+05
           0.000000    0.787402   40.157480
! side bearing vertical stiffness and damping
 18   4 -12141.0000  0.0000E+00  0.0000E+00  19671000.0000
           0.000000    0.024291    0.492087   39.370079
 19   2  0.0000E+00  1.9671E+04
           0.000000   39.370079
! longitudinal stiffness damping of paired primary suspension bushings
 20   2  0.0000E+00  1.0195E+07
           0.000000   39.370079
 21   2  0.0000E+00  90.05802
           0.000000   1.0
! lateral stiffness and damping of paired primary suspension bushings
 22   2  0.0000E+00  1.6186E+06
           0.000000   39.370079
 23   2  0.0000E+00  35.8835
           0.000000   1.0
! yaw stiffness and damping of paired primary suspension bushings
 24   2  0.0000E+00  3.6005E+05
           0.000000    0.001000
```

```
 25   2  0.0000E+00  182503
           0.000000    1.000000
!0vertical stiffness and damping of single0primary suspension bushing
 26   5 -10422.6    -9973.6     -9186.300   -8624.300   -7725.100
        -0.07874000 -0.03937000  0.000000    0.03937000  0.07874000
      2  0.0000E+00  67.991900
           0.000000   1.0
!0Traction rod shear0(vertical) stiffness and damping
 32   2  0.0000E+00006.7443E+030
           0.000000   39.370079
 33   2  0.0000E+00006.7443E+010
           0.000000   39.370079
!
!0Lat/Long Change of area stiffness00
  110      2     0.0    425.0
                 0.000    1.0
!Airbag vertical dAe/dz
  112     2   0.0    200.0
             0.0      1.0
!Airbag dummy long and lat00
  114     2   0.0      0.0
             0.0      1.0
!Airbag vertical pedestal stiffness00
  115    2    -1614000 0.00
             0.0      4.472437977
!Long/Lat dynamic shear stiffness - no stiffness00
  116    2    0.0      0.0
            0.0      1.0
!Airbag vertical reservoir stiffness00
  118     2    -16140  0.000
            0.0      4.356275304
!Orifice damping assuming a 15mm diameter00
  119  12   0   17.88501852     71.54007409     160.9651667     286.1602964
        643.8606668     1144.641185     1788.501852     3505.46363
        7154.007409     16096.51667     28616.02964
            0   0.196850394     0.393700787     0.590551181     0.787401575
        1.181102362     1.57480315      1.968503937     2.755905512
        3.937007874     5.905511811     7.874015748
! Very stiff connection of airbag to bolster. long and lat
  155   2    0.0   1e6
             0.0   1.0
  156   2    0.0   1e3
             0.0   1.0
!Long & lat0dynamic airbag connection0
  160   200 0.0    1000
            0.0    1.0
  161   2    0.0   500
             0.0   1.0
!Secondary0Lateral Damper
  162   2    0.0   50
             0.0   1.0
!Secondary Vertical Damper
  163   2    0.0   25
             0.0   1.0
!Anti-Roll Bar00
  164   2    0.0   3e7
             0.0   1.0
```

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\SYSTEM TITLE
Conical Spring, Bi-Level0Car, w/ 4-point secondary air spring suspension

Give the number of0bodies, then for each, list the number, name, up to 15
characters in single quotes, and0c.g. position, relative to a chosen datum,
followed by the number and0list of degrees of freedom required (from 1=x,
2=y, 3=z, 4=phi, 5=theta, 6=psi, 7=epsx, 8=epsy, 9=epsz),0 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, & Z00
          No. & DoF List             Mass, Roll, Pitch, & Yaw Inertia00
---------------------------------------------------------------------------
\BODY DATA
    9
    1     '0Car Body       '          -404.24410000      87
        6   1 2 3 4 5 6               282.3200     1.1024E6  2.5206E7  2.4851E7
    2     'AirBag Ld0'               -47.244100      0.0      35.0394
        5   1 2 3 4 6                 0.3626     1.70e2   0.0      1.70e2
    3     'AirBag Trl'              -761.244100      0.0      35.0394
        5   1 2 3 4 6                 0.3626     1.70e2   0.0      1.70e2
    4     '0Lead Bogie     '          -47.244100 00       24.015761
        6   1 2 3 4 5 6               14.73210  1.3893E+0400    1.2169E+0400
        2.5657E+04
    5     ' Trail Bogie    '         -761.244100 00       24.015761
        6   1 2 3 4 5 6               14.732100 1.3893E+04      1.2169E+04
        2.5657E+04
    6     '0Axle Number 1 '           0          0        18.503947
        5   1 2 3 4 6                 9.4788     1.0231E+0400    1.0709E+03
        1.0231E+04
    7     ' Axle Number 2 '           -94.488200 00       18.503947
        5   1 2 3 4 6                 9.478800  1.0231E+04      1.0709E+03
        1.0231E+0400
    8     '0Axle Number 3 '          -71400      0        18.503947
        5   1 2 3 4 6                 9.478800  1.0231E+04      1.0709E+03
        1.0231E+0400
    90    ' Axle Number 4 '          -808.488200 00       18.503947
        5   1 2 3 4 6                 9.478800  1.0231E+04      1.0709E+03
        1.0231E+04

For all bodies with flexible modes, give the position of the body geometric
center, in the X direction from the datum, its length, and the natural
frequencies (Hz) and damping ratios in twist, vertical, and lateral bending.

  Body #    X-Posn00  X-Length00 Nat Frequencies0    Damping Ratios
---------------------------------------------------------------------------

!\FLEXIBLE MODES
   1      -404.244100   1020        8.1000000      0.0000000      0.0000000
   0.050  0.000  0.000
!   4        -47.244100   127.5591   54.5000000      0.0000000      0.0000000
0.050  0.000  0.000
!   5       -761.244100   127.5591   54.5000000      0.0000000      0.0000000
0.050  0.000  0.000

Give the number of connections, then for each, list the number, name, up
to 15 characters in single quotes, a position relative to the chosen datum,
numbers for the bodies at each end, 0 for an earth in local track coords.,
a number indicating the degree of freedom, translational 1,2,3 or rotational
4,5,6, in x,y,z resp., including 2 for lateral wheel motion, and the type:
    1 - parallel pair of spring and damper characteristics
```

```
    2 - series pair of spring and damper characteristics
    3 - device with hysteresis between 2 PWL characteristics, e.g. carriage
        spring or load sensitive suspension
    4 - lateral/longitudinal suspension of the wheel on rail
    5 - connection force as a history of the distance moved
and the identification number for each of type 1, 2 and 3, the axle number
for type 4, input function number for type 5.

Note - single characteristics are treated as parallel pairs with the
       missing characteristic set to zero in the subsequent table.

Conn# ' 15 Char Name  '  Type  Body 1 & 2   Posn in X, Y, & Z   DoF  No.
-----------------------------------------------------------------------------
\CONNECTION DATA
  55
!
!Lead Truck
!Carbody to Airbag connections
!2point suspension
  2101  'LdCBtoAirbag Lft'   1.3  1  2  -47.2441  39.9607   38.6294    6  1
  2 3 4 5 6  108  108  109  110 110 110
  2102  'LdCBtoAirbag Rgt'   1.3  1  2  -47.2441 -39.9607   38.6294    6  1
  2 3 4 5 6  108  108  109  110 110 110
!Airbag to Bolster connections
  2103  'LdAirbag-Blst Lft'  1.1  2  4 -47.2441   39.9607   31.4494    3  1
  2  3  111  111  112
  2104  'LdAirbag-Blst Rgt'  1.1  2  4 -47.2441  -39.9607   31.4494    3  1
  2  3  111  111  112
!Change of area stiffness and shear
  2105  'LdCBtoLdBlst Lft'   1.1  1  4 -47.2441   39.9607   35.0394     3  1
  2  3 106  106  107
  2106  'LdCBtoLdBlst Rgt'   1.1  1  4 -47.2441  -39.9607   35.0394     3  1
  2  3 106  106  107
!lateral dynamic airbag connection
  2107  'CB-LdBagLftDyn'       1  1  2 -47.2441   39.9607   35.0394     2
  160
  2108  'LdBag-LdBlstLftDyn'   1  2  4 -47.2441   39.9607   35.0394     2
  161
  2109  'CB-LdBagRgtDyn'       1  1  2 -47.2441  -39.9607   35.0394     2
  160
  2110  'LdBag-LdBlstRgtDyn'   1  2  4 -47.2441  -39.9607   35.0394     2
  161
!Secondary Lateral Damper
  2111  'SLatDmpLd Lft   '  1  1 4  -53.2441   39.9607   35.0394  2 162
  2112  'SLatDmpLd Rgt   '  1  1 4  -53.2441  -39.9607   35.0394  2 162
!Secondary Vertical Damper
  2113  'SVrtDmpLd Lft   '  1  1 4  -41.2441   39.9607   35.0394  3 163
  2114  'SVrtDmpLd Rgt   '  1  1 4  -41.2441  -39.9607   35.0394  3 163
!Anti-Roll Bar
  2115  'Roll Bar Lead   '  1  1 4  -47.2441   0      12.0   4 164
!
!Trail Truck
!Carbody to Airbag connections
!2point suspension
  2201  'TrCBtoAirbag Lft'   1.3  1  3  -761.2441   39.9607   38.6294    6  1
  2 3 4 5 6  108  108  109  110 110 110
  2202  'TrCBtoAirbag Rgt'   1.3  1  3  -761.2441  -39.9607   38.6294    6  1
  2 3 4 5 6  108  108  109  110 110 110
!Airbag to Bolster connections
  2203  'TrAirbag-Blst Lft'  1.1  3  5  -761.2441   39.9607   31.4494    3  1
  2  3  111  111  112
  2204  'TrAirbag-Blst Rgt'  1.1  3  5  -761.2441  -39.9607   31.4494    3  1
  2  3  111  111  112
!Change of area stiffness and shear
```

```
  2205  'TrCBtoTrBlst Lft'   1.1  1  5  -761.2441   39.9607   35.0394    3  1
  2  3 106  106  107
  2206  'TrCBtoTrBlst Rgt'   1.1  1  5  -761.2441  -39.9607   35.0394    3  1
  2  3 106  106  107

  2207  'CB-TlBagLftDyn'       1  1  3  -761.2441   39.9607   35.0394     2
  160
  2208  'TlBag-TlBlstLftDyn'   1  3  5  -761.2441   39.9607   35.0394     2
  161
  2209  'CB-TlBagRgtDyn'       1  1  3  -761.2441  -39.9607   35.0394     2
  160
  2210  'TlBag-TlBlstRgtDyn'   1  3  5  -761.2441  -39.9607   35.0394     2
  161
!Secondary Lateral Damper
  2211  'SLatDmpTr Lft  '  1  1 5  -755.2441  39.9607   35.0394  2 162
  2212  'SLatDmpTr Rgt  '  1  1 5  -755.2441 -39.9607   35.0394  2 162
!Secondary Vertical Damper
  2213  'SVrtDmpTr Lft  '  1  1 5  -767.2441  39.9607   35.0394  3 163
  2214  'SVrtDmpTr Rgt  '  1  1 5  -767.2441 -39.9607   35.0394  3 163
!Anti-Roll Bar
  2215  'Roll Bar Trail '  1  1 5  -761.2441  0      12.0  4 164
!
! Secondary suspension bump stops
  15 'Bump Stop Lat 1'  1    1  4  -47.2441             0        28.6220627
     2         7
  16 'Bump Stop Lat 2'  1    1  5  -761.2441            0        28.6220627
     2         7
     'Bump Stop Vrt 1'  1    1  4  -35.8268             0        29.6063152
     3         8
  18 'Bump Stop Vrt 2'  1    1  4  -58.6614             0        29.6063152
     3         8
  19 'Bump Stop Vrt     1    1  5  -751.0079    -11.81103        29.6063152
     3         8
  20 'Bump Stop Vrt 4'  1    1  5  -771.4803     11.81103        29.6063152
     3         8
! Secondary suspension anti-roll bars
!  21 '  Roll Bar #1  '  1    1  4    -47.2441            0        12.598432
4        9
!  22 '  Roll Bar #2  '  1    1  5   -761.2441            0        12.598432
4        9
! Traction link longitudinal and shear stiffnesses
  23 'Traction Lnk #1'  1.1  1  4   -47.2441            0        18.503947   3
       1 2 3   10 11 12
  24 'Traction Lnk #2'  1.1  1  5  -761.2441            0        18.503947   3
       1 2 3   10 11 12
! Secondary lateral dampers
!  25 'Latrl Damper #1'  1    1  4  -56.2992    -16.535442      34.251987
2        13
!  26 'Latrl Damper #2'  1    1  5  -752.1890    16.535442      34.251987
2        13
! Primary longitudinal, lateral and vertical suspensions
  27 'Bogie#1-Axle 1L'  1.1  4  6    0          40.5118329     21.259854   3
       1 2 3   14 15 16
  28 'Bogie#1-Axle 1R'  1.1  4  6    0         -40.5118329     21.259854   3
       1 2 3   14 15 16
  29 'Bogie#1-Axle 2L'  1.1  4  7   -94.4882    40.5118329     21.259854   3
       1 2 3   14 15 16
  30 'Bogie#1-Axle 2R'  1.1  4  7   -94.4882   -40.5118329     21.259854   3
       1 2 3   14 15 16
  31 'Bogie#2-Axle 3L'  1.1  5  8   -714        40.5118329     21.259854   3
       1 2 3   14 15 16
  32 'Bogie#2-Axle 3R'  1.1  5  8   -714       -40.5118329     21.259854   3
       1 2 3      15 16
     'Bogie#2-Axle 4L'  1.1  5  9   -808.4882   40.5118329     21.259854
```

```
        1 2 3       15 16
     'Bogie#2-Axlee4R'  1.1   5  9   -808.4882ee -40.5118329ee   21.259854ee
        1 2 3   14 15 16
! Wheel/rail interaction elements
      ' Wheel/Rail 1L '  4    6       0           29.7637956     0       1
      ' Wheel/Rail 1R '  4    6       0          -29.7637956ee   0       1
  37  ' Wheel/Rail 2L '  4    7     -94.4882ee    29.7637956ee   0       2
  38  ' Wheel/Rail 2R '  4    7     -94.4882ee   -29.7637956ee   0       2
  39  ' Wheel/Rail 3L '  4    8     -714ee        29.7637956ee   0       3
  40  ' Wheel/Rail 3R '  4    8     -714ee       -29.7637956ee   0       3
  41  ' Wheel/Rail 4L '  4    9     -808.4882ee   29.7637956ee   0       4
  42  ' Wheel/Rail 4R '  4    9     -808.4882e   -29.7637956ee   0       4
! Soft Tow Rope: car body to ground longitudinal connectionee
  43 'Dummy Bdy-Grnd '  1     1  0    -404.2441   0        87       1       17
```

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).

```
 Paire#  Stiffness & Damping  F/S-extn.  F/S-comp.    K/D-parameters
----------------------------------------------------------------------------
\CHARACTERISTIC DATA
      7        10           0      2.25E+08     -2.25E+08ee
      8        11           0      2.25E+08     -2.25E+08ee
!      9        12           0      2.25E+08     -2.25E+08ee
     10        13           0      2.25E+08     -2.25E+08ee
     11        14           0      2.25E+08     -2.25E+08ee
     12        15           0      2.25E+08     -2.25E+08ee
!     13         0          16      2.25E+08     -2.25E+08ee
     14        17           0      2.25E+08     -2.25E+08ee
     15        18          19      2.25E+08     -2.25E+08ee
     16        20          21      2.25E+08     -2.25E+08ee
     17        22          23      2.25E+08     -2.25E+08ee
!Airbag shear static stiffnessee
  106   110    0   1.0e9      -1.0e9ee
!Airbag veritcal dAe/dz
  107   112    0   1.0e9ee    -1.0e9ee
!Dummy Lat & Long connectionee
  108   116   114   1.0e9      -1.0e9ee
!Airbag veritcal pedestal stiffness - Airbag vertical stiffnessee
  109   115    0   1.0e9      -1.0e9
!Dummy airbag roll (for roll moment due to shear)
  110  0    0    1.0e9      -1.0e9ee
!Long/Lat AB to Bolsteree
  111  155   156   1.0e9      -1.0e9ee
!Airbag vertical reservoir stiffness and orifice damping
  112  118   119   1.0e9ee   -1.0e9ee
!Dynamic long & lat airbag connection - Spring Damper in Seriesee
  160  160    0    1.0e9ee    -1.0e9ee
  161  0     161   1.0e9ee    -1.0e9ee
!Secondary Lateral Damper
  162  0  162  1e9 -1e9
!Secondary Lateral Damper
  163  0  163  1e9 -1e9
!Anti-Roll Baree
  164 164  0   1e9 -1e9
```

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
 2.E5  5.0E200  2.E5   5.0E2
     1          18.503947       .F.       0         0
     2          18.503947       .F.       0         0
     3          18.503947       .F.       0         0
     4          18.503947       .F.       0         0
```

For each piecewise linear function, list the identification number, the number of break points, and the ordinate, N or N-m, over abscissa, meters 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
!00Secondary Lateral Bump Stop Stiffness00
 10  12  0.0000E+00  0.0000E+00  1.1240E+02  2.6977E+02  4.7210E+0200
 7.6435E+02  1.2364E+03
         1.8434E+03  2.7876E+03  4.1590E+03  6.4071E+030 9.4195E+0300
           0.000000    0.472441    0.570866    0.6692910   0.76771700
           0.866142    0.964567
           1.062992    1.161417    1.259843    1.358268    1.456693
! Secondary Vertical Bump Stop Stiffness
 11   9 -5.9552E+04 -4.4108E+04 -3.3519E+04 -2.5583E+04 -1.8974E+04 -
 8.3854E+03 -6.6094E+03
         0.0000E+00  0.0000E+00
          -1.53543300 -1.45669300 -1.37795300 -1.29921300 -1.22047200 -
          1.14173200 -1.06299200
          -0.98425200 39.37007900
! Roll Bar Stiffness
! 12    2  0.0000E+00  6.6381E+06
!           0.000000    1.000000
! Traction Rod Longitudinal Stiffness
 13   2  0.0000E+00  3.3092E+06
           0.000000   39.370079
!00Traction Rod Lateral Stiffness00
 14   2  0.0000E+00  1.5737E+04
           0.000000   39.370079
!00Traction Rod Vertical Stiffness00
 15   2  0.0000E+00  3.3721E+04
           0.000000   39.370079
! Lateral Damper Characteristic
!001600 3  0.0000E+00  6.6094E+020 1.2679E+03
!           0.000000    1.968504   41.338583
!00Primary Longitudinal Stiffness00
 17   2  0.0000E+00  1.0341E+06
           0.000000   39.370079
!00Primary Lateral Stiffness00
 18   2  0.0000E+00  4.4962E+05
           0.000000   39.370079
!00Primary Lateral Damping ( 5% critical00
 19   2  0.0000E+00  1.0791E+03
           0.000000   39.370079
!00Primary Vertical Stiffness00
 20   2   -15082.100       0
           0.000000    2.641267
!00Primary Vertical Damping ( 5% critical )
 21   2  0.0000E+00  7.6435E+02
           0.000000   39.370079
```

```
 22   2  0.0000E+00  5.9125E+04
           0.000000   39.370079
 23   2  0.0000E+00  5.9125E+03
           0.000000   39.370079
! Lat/Long Change of area stiffness
  110       2      0.0     425.0
                   0.0       1.0
!Airbag vertical dAe/dz
  112      2    0.0     200.0
             0.0      1.0
!Airbag dummy long and lat
  114      2    0.0       0.0
             0.0      1.0
!Airbag vertical pedestal stiffness
  115     2    -27390    0.0
             0.0      4.957172001
!Long/Lat dynamic shear stiffness - no stiffness
  116    2   0.0       0.0
            0.0      1.0
!Airbag vertical reservoir stiffness
  118    2    -27390  0.0
            0.0      4.82841487
!Orifice damping assuming a 15mm diameter
  119  12   0   27.38345148     109.5338059     246.4510633     438.1352237
        985.8042534     1752.540895     2738.345148     5367.156491
        10953.38059     24645.10633     43813.52237
            0   0.196850394     0.393700787     0.590551181     0.787401575
        1.181102362     1.57480315      1.968503937     2.755905512
        3.937007874     5.905511811     7.874015748
! Very stiff connection of airbag to bolster. long and lat
  155    2    0.0   1e6
              0.0   1.0
  156    2    0.0   1e3
              0.0   1.0
!Long & lat dynamic airbag connection
  160    2    0.0  2500.0
              0.0   1.0
  161    2    0.0  500.0
              0.0   1.0
!Secondary Lateral Damper
  162    2    0.0  50
              0.0   1.0
!Secondary Vertical Damper
  163    2    0.0  25
              0.0   1.0
!Anti-Roll Bar
  164    2    0.0   3e7
              0.0   1.0
```

```
System file (.SYS) for NUCARS Version 2.0
==========================================

\SYSTEM TITLE
Conical Spring, Single-Level Car w/ 4-point secondary air spring suspension

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
    9
    1     ' Car Body      '            -404.2441  0        64.17
       6   1 2 3 4 5 6                 163.17      4.2159E5  1.4352E7  1.4363E7
    2     'AirBag Ld'                 -47.2441      0.0        35.0394
       5   1 2 3 4 6                    0.3626      1.70e2   0.0      1.70e2
    3     'AirBag Trl'               -761.2441      0.0        35.0394
       5   1 2 3 4 6                    0.3626      1.70e2   0.0      1.70e2
    4     'Lead Bogie     '            -47.2441  0        24.015761
       6   1 2 3 4 5 6                  14.7321  1.3893E+04      1.2169E+04
       2.5657E+04
    5     ' Trail Bogie   '           -761.2441  0        24.015761
       6   1 2 3 4 5 6                  14.7321  1.3893E+04      1.2169E+04
       2.5657E+04
    6     'Axle Number 1 '               0          0        18.503947
       5   1 2 3 4 6                    9.4788    1.0231E+04      1.0709E+03
       1.0231E+04
    7     'Axle Number 2 '            -94.4882  0        18.503947
       5   1 2 3 4 6                    9.4788    1.0231E+04      1.0709E+03
       1.0231E+04
    8     'Axle Number 3 '           -714          0        18.503947
       5   1 2 3 4 6                    9.4788    1.0231E+04      1.0709E+03
       1.0231E+04
    9     'Axle Number 4 '           -808.4882  0        18.503947
       5   1 2 3 4 6                    9.4788    1.0231E+04      1.0709E+03
       1.0231E+04

For all bodies with flexible modes, give the position of the body geometric
center, in the X direction from the datum, its length, and the natural
frequencies (Hz) and damping ratios in twist, vertical, and lateral bending.

  Body #    X-Posn  X-Length Nat Frequencies    Damping Ratios
-----------------------------------------------------------------------------

!\FLEXIBLE MODES
   1      -404.2441   1020         8.1000000      0.0000000      0.0000000
   0.050  0.000  0.000
!   4        -47.2441   127.5591   54.5000000      0.0000000      0.0000000
0.050  0.000  0.000
!   5      -761.2441   127.5591   54.5000000      0.0000000      0.0000000
0.050  0.000  0.000

Give the number of connections, then for each, list the number, name, up
to 15 characters in single quotes, a position relative to the chosen datum,
numbers for the bodies at each end, 0 for an earth in local track coords.,
a number indicating the degree of freedom, translational 1,2,3 or rotational
4,5,6, in x,y,z resp., including 2 for lateral wheel motion, and the type:
    1- parallel pair of spring and damper characteristics
```

- - -

```
    2 - series pair of spring and damper characteristics
    3 - device with hysteresis between 2 PWL characteristics, e.g. carriage
        spring or load sensitive suspension
    4 - lateral/longitudinal suspension of the wheel on rail
    5 - connection force as a history of the distance moved
and the identification number for each of type 1, 2 and 3, the axle number
for type 4, input function number for type 5.

Note - single characteristics are treated as parallel pairs with the
       missing characteristic set to zero in the subsequent table.

Conn# ' 15 Char Name   '  Type  Body 1 & 2   Posn in X, Y, & Z   DoF  No.
---------------------------------------------------------------------------
\CONNECTION DATA
  55
!
!Lead Truck
!Carbody to Airbag connections
!2point suspension
  2101  'LdCBtoAirbag Lft'       1  2  -47.2441  39.9607   38.6294    6  1
  2 3 4 5 6  108  108  109  110 110 110
  2102  'LdCBtoAirbag Rgt'   1.3  1  2  -47.2441 -39.9607   38.6294    6  1
  2 3 4 5 6  108  108  109  110 110 110
!Airbag to Bolster connections
  2103  'LdAirbag-Blst Lft'  1.1  2  4 -47.2441   39.9607   31.4494    3  1
  2  3  111  111  112
  2104  'LdAirbag-Blst Rgt'  1.1  2  4 -47.2441  -39.9607   31.4494    3  1
  2  3  111  111  112
!Change of area stiffness and shear
  2105  'LdCBtoLdBlst Lft'   1.1  1  4 -47.2441   39.9607   35.0394     3  1
  2  3 106  106  107
  2106  'LdCBtoLdBlst Rgt'   1.1  1  4 -47.2441  -39.9607   35.0394     3  1
  2  3 106  106  107
!lateral dynamic airbag connection
  2107  'CB-LdBagLftDyn'       1  1  2 -47.2441   39.9607   35.0394     2
  160
  2108  'LdBag-LdBlstLftDyn'   1  2  4 -47.2441   39.9607   35.0394     2
  161
  2109  'CB-LdBagRgtDyn'       1  1  2 -47.2441  -39.9607   35.0394     2
  160
  2110  'LdBag-LdBlstRgtDyn'   1  2  4 -47.2441  -39.9607   35.0394     2
  161
!Secondary Lateral Damper
  2111  'SLatDmpLd Lft   '  1  1 4  -53.2441   39.9607   35.0394  2 162
  2112  'SLatDmpLd Rgt   '  1  1 4  -53.2441  -39.9607   35.0394  2 162
!Secondary Vertical Damper
  2113  'SVrtDmpLd Lft   '  1  1 4  -41.2441   39.9607   35.0394  3 163
  2114  'SVrtDmpLd Rgt   '  1  1 4  -41.2441  -39.9607   35.0394  3 163
!Anti-Roll Bar
  2115  'Roll Bar Lead   '  1  1 4  -47.2441   0       12.0  4 164
!
!Trail Truck
!Carbody to Airbag connections
!2point suspension
  2201  'TrCBtoAirbag Lft'   1.3  1  3  -761.2441   39.9607   38.6294    6  1
  2 3 4 5 6  108  108  109  110 110 110
  2202  'TrCBtoAirbag Rgt'        1  3  -761.2441  -39.9607   38.6294    6  1
  2 3 4 5 6  108  108  109  110 110 110
!Airbag to Bolster connections
  2203  'TrAirbag-Blst Lft'  1.1  3  5  -761.2441   39.9607   31.4494    3  1
  2  3  111  111  112
  2204  'TrAirbag-Blst Rgt'  1.1  3  5  -761.2441  -39.9607   31.4494    3  1
  2  3  111  111  112
!Change of area stiffness and shear
```

```
!lateral dynamic airbag connection
  2207  'CB-TlBagLftDyn'       1  1  3  -761.2441   39.9607   35.0394      2
  160
  2208  'TlBag-TlBlstLftDyn'   1  3  5  -761.2441   39.9607   35.0394      2
  161
  2209  'CB-TlBagRgtDyn'       1  1  3  -761.2441  -39.9607   35.0394      2
  160
  2210  'TlBag-TlBlstRgtDyn'   1  3  5  -761.2441  -39.9607   35.0394      2
  161
!Secondary Lateral Damper
  2211  'SLatDmpTr Lft  '  1  1 5  -755.2441  39.9607   35.0394  2 162
  2212  'SLatDmpTr Rgt  '  1  1 5  -755.2441 -39.9607   35.0394  2 162
!Secondary Vertical Damper
  2213  'SVrtDmpTr Lft  '  1  1 5  -767.2441  39.9607   35.0394  3 163
  2214  'SVrtDmpTr Rgt  '  1  1 5  -767.2441 -39.9607   35.0394  3 163
!Anti-Roll Bar
  2215  'Roll Bar Trail '  1  1 5  -761.2441  0      12.0  4 164
!
! Secondary suspension bump stops
  15 'Bump Stop Lat 1'  1    1  4  -47.2441            0       28.6220627
      2        7
  16 'Bump Stop Lat 2'  1    1  5  -761.2441           0       28.6220627
      2        7
  17 'Bump Stop Vrt 1'  1    1  4  -35.8268            0       29.6063152
      3        8
  18 'Bump Stop Vrt 2'  1    1  4  -58.6614            0       29.6063152
      3        8
  19 'Bump Stop Vrt 3'  1    1  5  -751.0079    -11.81103       29.6063152
      3        8
  20 'Bump Stop Vrt 4'  1    1  5  -771.4803     11.81103       29.6063152
      3        8
! Secondary suspension anti-roll bars
!  21 '  Roll Bar #1  '  1    1  4   -47.2441           0       12.598432
4       9
!  22 '  Roll Bar #2  '  1    1  5   -761.2441          0       12.598432
4       9
! Traction link longitudinal and shear stiffnesses
  23 'Traction Lnk #1'  1.1  1  4   -47.2441           0       18.503947   3
      1 2 3   10 11 12
  24 'Traction Lnk #2'  1.1  1  5  -761.2441           0       18.503947   3
      1 2 3   10 11 12
! Secondary lateral dampers
!  25 'Latrl Damper #1'  1    1  4  -56.2992    -16.535442      34.251987
2       13
!  26 'Latrl Damper #2'  1    1  5  -752.1890    16.535442      34.251987
2       13
! Primary longitudinal, lateral and vertical suspensions
  27 'Bogie#1-Axle 1L'  1.1  4  6    0           40.5118329     21.259854   3
      1 2 3   14 15 16
  28 'Bogie#1-Axle 1R'  1.1  4  6    0          -40.5118329     21.259854   3
      1 2 3   14 15 16
  29 'Bogie#1-Axle 2L'  1.1  4  7   -94.4882     40.5118329     21.259854   3
      1 2 3   14 15 16
  30 'Bogie#1-Axle 2R'  1.1  4  7   -94.4882    -40.5118329     21.259854   3
      1 2 3   14 15 16
  31 'Bogie#2-Axle 3L'  1.1  5  8   -714         40.5118329     21.259854   3
      1 2 3   14 15 16
  32 'Bogie#2-Axle 3R'  1.1  5  8   -714        -40.5118329     21.259854   3
      1 2 3   14 15 16
  33 'Bogie#2-Axle 4L'  1.1  5  9   -808.4882    40.5118329     21.259854   3
```

```
      1 2 3   14 15 16
   'Bogie#2-Axle 4R'  1.1  5  9   -808.4882ee -40.5118329ee   21.259854ee
      1 2 3   14 15 16
! Wheel/rail interaction elements
  35 ' Wheel/Rail 1L '  4    6       0           29.7637956      0       1
  36 ' Wheel/Rail 1R '  4    6       0          -29.7637956ee    0       1
     ' Wheel/Rail 2L '  4    7     -94.4882ee    29.7637956ee    0       2e
  38 ' Wheel/Rail 2R '  4    7     -94.4882ee   -29.7637956ee    0       2
  39 ' Wheel/Rail 3L '  4    8     -714ee        29.7637956ee    0       3
  40 ' Wheel/Rail 3R '  4    8     -714ee       -29.7637956ee    0       3
  41 ' Wheel/Rail 4L '  4    9     -808.4882ee   29.7637956ee    0       4
  42 ' Wheel/Rail 4R '  4    9     -808.4882ee  -29.7637956ee    0       4
! Soft Tow Rope: car body to ground longitudinal connection
  43 'Dummy Bdy-Grnd '  1    1  0   -404.2441ee 0e      64.17      1       17
```

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).

```
 Paire#  Stiffness & Damping  F/S-extn.  F/S-comp.    K/D-parameters
----------------------------------------------------------------------------
\CHARACTERISTIC DATA
     7       10          0     2.25E+08     -2.25E+08ee
     8       11          0     2.25E+08     -2.25E+08ee
!     9       12          0     2.25E+08     -2.25E+08ee
    10       13          0     2.25E+08     -2.25E+08ee
    11       14          0     2.25E+08     -2.25E+08ee
    12       15          0     2.25E+08     -2.25E+08ee
!    13        0         16     2.25E+08     -2.25E+08ee
    14       17          0     2.25E+08     -2.25E+08ee
    15       18         19     2.25E+08     -2.25E+08ee
    16       20         21     2.25E+08     -2.25E+08ee
    17       22         23     2.25E+08     -2.25E+08ee
!Airbag shear static stiffnessee
  106   110    0   1.0e9ee    -1.0e9ee
!Airbag veritcal dAe/dz
  107   112    0   1.0e9      -1.0e9ee
!Dummy Lat & Long connectionee
  108   116   114   1.0e9ee    -1.0e9ee
!Airbag veritcal pedestal stiffness - Airbag vertical stiffnessee
  109   115    0   1.0e9      -1.0e9ee
!Dummy airbag roll (for roll moment due to shear)
  110  0     0    1.0e9      -1.0e9ee
!Long/Lat AB to Bolsteree
  111  155    156    1.0e9ee    -1.0e9ee
!Airbag vertical reservoirestiffness and orifice damping
  112  118    119    1.0e9      -1.0e9ee
!Dynamic long & lat airbageconnection - Spring Damper in Seriese
  160  160    0     1.0e9      -1.0e9ee
  161  0     161   1.0e9      -1.0e9ee
!Secondary Lateral Damper
  162  0  162  1e9 -1e9
!Secondary Lateral Damper
  163  0  163  1e9 -1e9
!Anti-Roll Baree
  164 164  0ee 1e9 -1e9e
```

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
 2.E5  5.0E2    2.E5   5.0E2
     1          18.503947        .F.       0         0
     2          18.503947        .F.       0         0
     3          18.503947        .F.       0         0
     4          18.503947        .F.       0         0
```

For each piecewise linear function, list the identification number, the number of break points, and the ordinate, N or N-m, over abscissa, meters 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
! Secondary Lateral Bump Stop Stiffness
 10  12  0.0000E+00  0.0000E+00  1.1240E+02  2.6977E+02  4.7210E+02
 7.6435E+02  1.2364E+03
         1.8434E+03  2.7876E+03  4.1590E+03  6.4071E+03  9.4195E+03
           0.000000    0.472441    0.570866    0.669291    0.767717
           0.866142    0.964567
           1.062992    1.161417    1.259843    1.358268    1.456693
! Secondary Vertical Bump Stop Stiffness
 11   9 -5.9552E+04 -4.4108E+04 -3.3519E+04 -2.5583E+04 -1.8974E+04 -
 8.3854E+03 -6.6094E+03
         0.0000E+00  0.0000E+00
          -1.535433   -1.456693   -1.377953   -1.299213   -1.220472   -
          1.141732   -1.062992
          -0.984252   39.370079
! Roll Bar Stiffness
! 12    2  0.0000E+00  6.6381E+06
!            0.000000    1.000000
! Traction Rod Longitudinal Stiffness
 13   2  0.0000E+00  3.3092E+06
           0.000000   39.370079
! Traction Rod Lateral Stiffness
 14   2  0.0000E+00  1.5737E+04
           0.000000   39.370079
! Traction Rod Vertical Stiffness
 15   2  0.0000E+00  3.3721E+04
           0.000000   39.370079
! Lateral Damper Characteristic
! 16    3  0.0000E+00  6.6094E+02  1.2679E+03
!            0.000000    1.968504   41.338583
! Primary Longitudinal Stiffness
      2  0.0000E+00  1.0341E+06
           0.000000   39.370079
! Primary Lateral Stiffness
 18   2  0.0000E+00  4.4962E+05
           0.000000   39.370079
! Primary Lateral Damping ( 5% critical )
 19   2  0.0000E+00  1.0791E+03
           0.000000   39.370079
! Primary Vertical Stiffness
 20   2   -9331.77        0
           0.000000    1.6342351
! Primary Vertical Damping ( 5% critical )
 21   2  0.0000E+00  7.6435E+02
           0.000000   39.370079
```

```
 22   2  0.0000E+00  5.9125E+04
          0.000000   39.370079
 23   2  0.0000E+00  5.9125E+03
          0.000000   39.370079
! Lat/Long Change of area stiffness
  110      2     0.0    425.0
                 0.0     1.0
!Airbag vertical dAe/dz
  112     2   0.0    200.0
             0.0     1.0
!Airbag dummy long and lat
  114     2   0.0     0.0
             0.0     1.0
!Airbag vertical pedestal stiffness
  115    2   -16140   0.0
             0.0     4.472437977
!Long/Lat dynamic shear stiffness - no stiffness
  116    2   0.0     0.0
            0.0     1.0
!Airbag vertical reservoir stiffness
  118     2   -16140  0.0
            0.0      4.356275304
!Orifice damping assuming a 15mm diameter
  119  12   0   17.88501852     71.54007409     160.9651667     286.1602964
        643.8606668     1144.641185     1788.501852     3505.46363
        7154.007409     16096.51667     28616.02964
            0   0.196850394     0.393700787     0.590551181     0.787401575
        1.181102362     1.57480315      1.968503937     2.755905512
        3.937007874     5.905511811     7.874015748
! Very stiff connection of airbag to bolster. long and lat
  155   2   0.0   1e6
            0.0   1.0
  156   2   0.0   1e3
            0.0   1.0
!Long & lat dynamic airbag connection
  160   2   0.0   1000
            0.0   1.0
  161   2   0.0   500
            0.0   1.0
!Secondary Lateral Damper
  162   2   0.0   50
            0.0   1.0
!Secondary Vertical Damper
  163   2   0.0   25
            0.0   1.0
!Anti-Roll Bar
  164   2   0.0   3e7
            0.0   1.0
```

```
System file (.SYS) for NUCARS Version 2004
==========================================

\SYSTEM TITLE
Loaded 100T Hopper Car w/Roller Side Bearings, NUCARS 2004, Rev. 04/01/04 RJW

Up graded Model
05/29/97  Added Long DoF's
11/25/98  Add fore/aft centerplate connections to allow bolster pitch
11/25/98  Divide main springs into 4
11/25/98  2 Surface friction elements for each Bearing Adapter
11/27/98  All bodies have all DOFs
11/28/98  Add centerplate Lat/Long rim friction elements
11/28/98  2.5E5 Vertical rails
11/29/98  Initial offsets on all Vertical PWLS
03/18/99  Standard Version NUCARS 2.2
11/13/00  Type 6.7 Wedge Model for NUCARS 2.3
10/18/01  Updated force accumulators for cnetrplate friction elements
01/21/02  Lift off characteristic for bearing adaptors
03/01/02  Lift off Characteristic for longitudinal/lateral centerplate rim
friction
04/14/04  Gap element dampers for friction sliders, type 1.3 connections for
          secondary suspension, 5e5 stiffness on bearing adapters for better
          load equalization results


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, & Z00
           No. & DoF List           Mass, Roll, Pitch, & Yaw Inertia00
-------------------------------------------------------------------------
\BODY DATA
   11
    100 ' Full Main Body'          -278.000     0.0       83.0
       6   1  2  3  4  5  6   630.79    1.84E06   1.67E07   1.67E07
    2   'Leading Bolster'            -35.000     0.0       18.0
       6   1  2  3  4  5  6     3.78    2.76E03   2.04E2    2.76E03
    3   'Trailng Bolster'           -521.000     0.0       18.0
       6   1  2  3  4  5  6     3.78    2.76E03   2.04E2    2.76E03
    4   'Lead Lft Sframe'            -35.000    39.5       18.0
       6   1  2  3  4  5  6     2.98    9.0E2     1.37E03   1.37E03
    5   'Lead Rgt Sframe'            -35.000   -39.5       18.0
       6   1  2  3  4  5  6     2.98    9.0E2     1.37E03   1.37E03
    6   'Trail Lt Sframe'           -521.000    39.5       18.0
       6   1  2  3  4  5  6     2.98    9.0E2     1.37E03   1.37E03
    7   'Trail Rt Sframe'           -521.000               18.0
       6   1  2  3  4  5  6     2.98    9.0E2     1.37E03   1.37E03
    800 ' Axle number 1 '              0.0       0.0       18.0
       5   1  2  3  4     6     7.73    5.89E0300 1.50E030  5.89E03
    9   '0Axle number 2 '            -70.000     0.0       18.0
       5   1  2  3  4     60            5.89E03   1.50E03   5.89E03
   10   '00Axle number 3 '          -486.000     0.0       18.0
       5   1  2  3  4     6     7.73    5.89E03   1.50E03   5.89E03
   11   ' Axle number 4 '           -556.000     0.0       18.0
       5   1  2  3  4     6             5.89E03   1.50E03   5.89E03

\CONNECTION DATA
   109
!0Location of Couplers to Ground, Set to 1E1 lb/in00
```

```
!
!
! ********************** 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   -35.0     8.0    22.7   2 1   3
 102   'Ld CB-Bl LgY LR'   6.2   1   2   -35.0    -8.0    22.7   2 1   3
 103   'Ld CB-Bl LtX Fr'   6.2   2   1   -27.0     0.0    22.7   1 2   3
 104   'Ld CB-Bl LtX Tr'   6.2   1   2   -43.0     0.0    22.7   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   -27.0     0.0    22.7   3 1 2   4
 106   'Ld CB-Bl Vt/Y B'   6.5   1   2   -43.0     0.0    22.7   3 1 2   4
 107   'Ld CB-Bl Vt/X L'   6.5   1   2   -35.0     8.0    22.7   3 1 2   4
 108   'Ld CB-Bl Vt/X R'   6.5   1   2   -35.0    -8.0    22.7   3 1 2   4
! Lead truck vertical centerplate dampers, gap connection
 109   'Ld CB-Bl Vt/Y F'   1.2   1   2   -27.0     0.0    22.7   3  5
 110   'Ld CB-Bl Vt/Y B'   1.2   1   2   -43.0     0.0    22.7   3  5
 111   'Ld CB-Bl Vt/X L'   1.2   1   2   -35.0     8.0    22.7   3  5
 112   'Ld CB-Bl Vt/X R'   1.2   1   2   -35.0    -8.0    22.7   3  5
! Lead Truck Vertical roller side bearing connections using a gap element
 113   'Ld Bol SB Lt Vt'   1.2   1   2   -35.0    25.0    27.8    3    6
 114   'Ld Bol SB Rt Vt'   1.2   1   2   -35.0   -25.0    27.8    3    6
! Lead Truck Constant Contact Side Bearings
! 115   'Ld Bol SB Lt Vt'   6.2   1   2   -35.0    25.0    27.8    3 1  7
! 116   'Ld Bol SB Rt Vt'   6.2   1   2   -35.0   -25.0    27.8    3 1  7
! Lead truck Long.,Pitch, and Yaw bolster to side frame connections
 117   'Ld L Bol-SF LPY'   1.1   2  4 -35.0  39.5 18.0  3  1 5 6  8 9 10
 118   'Ld R Bol-SF LPY'   1.1   2  5 -35.0 -39.5 18.0  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 -31.25  35.75 13.0  3  2 3 4  11 12 13
 120   'Ld R Bol-SF V 1'   1.3   2  5 -31.25 -35.75 13.0  3  2 3 4  11 12 13
 121   'Ld L Bol-SF V 2'   1.3   2  4 -31.25  43.25 13.0  3  2 3 4  11 12 13
 122   'Ld R Bol-SF V 2'   1.3   2  5 -31.25 -43.25 13.0  3  2 3 4  11 12 13
 123   'Ld L Bol-SF V 3'   1.3   2  4 -38.75  35.75 13.0  3  2 3 4  11 12 13
 124   'Ld R Bol-SF V 3'   1.3   2  5 -38.75 -35.75 13.0  3  2 3 4  11 12 13
 125   'Ld L Bol-SF V 4'   1.3   2  4 -38.75  43.25 13.0  3  2 3 4  11 12 13
 126   'Ld R Bol-SF V 4'   1.3   2  5 -38.75 -43.25 13.0  3  2 3 4  11 12 13
! Lead Truck 2D Friction wedge connection between bolster and side frame
 127   'Ld Bol-SF LL Wg'   6.7   2   4   -26.5    39.5    18.0   3 2  14
 128   'Ld Bol-SF LR Wg'   6.7   2   5   -26.5   -39.5    18.0   3 2  14
 129   'Ld Bol-SF TL Wg'   6.7   2   4   -43.5    39.5    18.0   3 2  14
 130   'Ld Bol-SF TR Wg'   6.7   2   5   -43.5   -39.5    18.0   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     0.0    42.5    22.5   3 1 2  15
 132   'SdFm-Ax 1 L V R'   6.5   4   8     0.0    36.5    22.5   3 1 2  15
 133   'SdFm-Ax 1 R V R'   6.5   5   8     0.0   -42.5    22.5   3 1 2  15
 134   'SdFm-Ax 1 R V L'   6.5   5   8     0.0   -36.5    22.5   3 1 2  15
 135   'SdFm-Ax 2 L V L'   6.5   4   9   -70.0    42.5    22.5   3 1 2  15
 136   'SdFm-Ax 2 L V R'   6.5   4   9   -70.0    36.5    22.5   3 1 2  15
 137   'SdFm-Ax 2 R V R'   6.5   5   9   -70.0   -42.5    22.5   3 1 2  15
 138   'SdFm-Ax 2 R V L'   6.5   5   9   -70.0   -36.5    22.5   3 1 2  15
! Lead Truck Vertical dampers for surface friction elements
 139   'SdFm-Ax 1 L V L'   1.2   4   8     0.0    42.5    22.5   3  16
 140   'SdFm-Ax 1 L V R'   1.2   4   8     0.0    36.5    22.5   3  16
 141   'SdFm-Ax 1 R V R'   1.2   5   8     0.0   -42.5    22.5   3  16
 142   'SdFm-Ax 1 R V L'   1.2   5   8     0.0   -36.5    22.5   3  16
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        'SdFm-Ax 2 L V L'   1.222 42  9   -70.022  42.5     22.5    3  16
  144   'SdFm-Ax 2 L V R'   1.222 4   9   -70.022  36.5     22.5    3  16
  145   'SdFm-Ax 2 R V R'   1.222 5   9   -70.022 -42.522   22.5    3  16
  146   'SdFm-Ax 2 R V L'   1.222 52  9   -70.022 -36.522   22.5    3  16
! Lead truck side frame to axle longitudinal, lateral and yaw Stops
  147   'SdFm-Ax 1 L V L'   1.1    4   8     0.0    39.5 22.5  3  1 2 6      18 19
  148   'SdFm-Ax 1 R V R'   1.1    5   8     0.0   -39.5 22.5  3  1 2 6  17 18 1922
  149   'SdFm-Ax 2 L V L'   1.1    4   9  -70.022 39.5 22.5  3  1 2 62 17 18 19
  150   'SdFm-Ax 2 R V R'   1.1    5   9  -70.0   -39.5 22.5  3  1 2 6  17 18 1922
! Lead Truck Wheel/rail connections
  151   'Ax 1 Lt Wh/Rail'    4    8          0.0     29.75    0.0     1
  152   'Ax 1 Rt Wh/Rail'    4    8          0.0    -29.7522  0.0     1
  153   'Ax 2 Lt Wh/Rail'    4    9        -70.022  29.7522  0.0     2
  154   'Ax 2 Rt Wh/Rail'    4    9        -70.022 -29.7522  0.0     2
  155   'Dummy Ctr Plt 1'   1.1   1    2   -35.022 0.0   22.7   3 4 5 6 20 20 202
!
! ************************ TRAILING TRUCK *********************************22
!
! 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  -521.022   8.0     22.7   2 1    3
  202   'Tr CB-Bl LgY LR'   6.2   1    3  -521.022  -8.022   22.7   2 1    3
  203   'Tr CB-Bl LtX Fr'   6.2   3    1  -513.022   0.0     22.7   1 2    3
  204   'Tr CB-Bl LtX Tr'   6.2   1    3  -529.022   0.0     22.7   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  -513.022   0.0     22.7   3 1 2    4
  206   'Tr CB-Bl Vt/Y B'   6.5   1    3  -529.022   0.0     22.7   3 1 2    4
  207   'Tr CB-Bl Vt/X L'   6.5   1    3  -521.022   8.0     22.7   3 1 2    4
  208   'Tr CB-Bl Vt/X R'   6.5   1    3  -521.022  -8.022   22.7   3 1 2    4
! Trail truck vertical centerplate dampers, gap connection
  209   'Tr CB-Bl Vt/Y F'   1.2   1    3  -513.022   0.0     22.7   3  5
  210   'Tr CB-Bl Vt/Y B'   1.2   1    3  -529.022   0.0     22.7   3  5
  211   'Tr CB-Bl Vt/X L'   1.2   1    3  -521.022   8.0     22.7   3  5
  212   'Tr CB-Bl Vt/X R'   1.2   1    3  -521.022  -8.022   22.7   3  5
! Trail Truck Vertical roller side bearing connections using a gap element
  213   'Tr Bol SB Lt Vt'   1.2   1    3  -521.022  25.0     27.8    3    6
  214   'Tr Bol SB Rt Vt'   1.2   1    3  -521.022 -25.022   27.8    3    6
! Trail Lead Truck Constant Contact Side Bearings
! 215   'Tr Bol SB Lt Vt'   6.2   1    3  -521.022  25.0     27.8    3 1  7
! 216   'Tr Bol SB Rt Vt'   6.2   1    3  -521.022 -25.022   27.8    3 1  7
! Trail truck Long.,Pitch, and Yaw bolster to side frame connections
  217   'Tr L Bol-SF LPY'   1.1   3  6  -521.0   39.5  18.0  3 1 5 6 8 9 1022
  218   'Tr R Bol-SF LPY'   1.1   3  7  -521.0 -39.5  18.0  3 1 5 6 8 9 1022
! 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  -517.25   35.75 13.0  3   2 3 42211 12 132
  220   'Tr R Bol-SF V 1'   1.3   3  7  -517.25 -35.75 13.0  3   2 3 4   11 12 1322
  221   'Tr L Bol-SF V 2'   1.3   3  6  -517.25   43.25 13.0  3   2 3 4   11 12 1322
  222   'Tr R Bol-SF V 2'   1.3   3  7  -517.25 -43.25 13.0  3   2 3 4   11 12 1322
  223   'Tr L Bol-SF V 3'   1.3   3  6  -524.75   35.75 13.0  3   2 3 42211 12 132
  224   'Tr R Bol-SF V 3'   1.3   3  7  -524.75 -35.75 13.0  3   2 3 4   11 12 1322
  225   'Tr L Bol-SF V 4'   1.3   3  6  -524.75   43.25 13.0  3   2 3 4   11 12 1322
  226   'Tr R Bol-SF V 4'   1.3   3  7  -524.75 -43.25 13.0  3   2 3 4   11 12 1322
! Trail Truck 2D Friction wedge connection between bolster and side frame
  227   'Tr Bol-SF LL Wg'   6.7   3   6  -512.522  39.5    18.0    3 2  14
  228   'Tr Bol-SF LR Wg'   6.7   3   7  -512.522 -39.522  18.0    3 2  14
  229   'Tr Bol-SF TL Wg'   6.7   3   6  -529.522  39.5    18.0    3 2  14
  230   'Tr Bol-SF TR Wg'   6.7   3   7  -529.522 -39.522  18.0    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  -486.0     42.5     22.5    3 1 2  15
  232   'SdFm-Ax 3 L V R'   6.5   6  10  -486.022   36.5     22.5    3 1 2  15
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  233  'SdFm-Ax 3 R V R'   6.5   7  10  -486.0ee -42.5ee  22.5   3 1 2  15
  234  'SdFm-Ax 3 R V L'   6.5   7  10  -486.0ee -36.5ee  22.5   3 1 2  15
  235  'SdFm-Ax 4 L V L'   6.5   6  11  -556.0ee  42.5    22.5   3 1 2  15
  236  'SdFm-Ax 4 L V R'         6  11  -556.0ee  36.5    22.5   3 1 2  15
  237  'SdFm-Ax 4 R V R'   6.5   7  11  -556.0ee -42.5ee  22.5   3 1 2  15
  238  'SdFm-Ax 4 R V L'   6.5   7  11  -556.0ee -36.5ee  22.5   3 1 2  15
! Trail Truck Vertical dampers for surface friction elements
  239  'SdFm-Ax 3 L V L'   1.2   6  10  -486.0ee  42.5    22.5   3   16
  240  'SdFm-Ax 3 L V R'   1.2   6  10  -486.0ee  36.5    22.5   3   16
  241  'SdFm-Ax 3 R V R'   1.2   7  10  -486.0ee -42.5ee  22.5   3   16
  242  'SdFm-Ax 3 R V L'   1.2   7  10  -486.0ee -36.5ee  22.5   3   16
  243  'SdFm-Ax 4 L V L'   1.2   6  11  -556.0ee  42.5ee  22.5   3   16
       'SdFm-Ax 4 L V R'   1.2   6  11  -556.0ee  36.5ee  22.5   3   16
  245  'SdFm-Ax 4 R V R'   1.2   7  11  -556.0ee -42.5ee  22.5   3   16
  246  'SdFm-Ax 4 R V L'   1.2   7  11  -556.0ee -36.5ee  22.5   3   16
! Trail truck side frame to axle longitudinal, lateral and yaw Stops
       'SdFm-Ax 3 L V L'   1.1   6  10  -486.0ee  39.5   22.5  3 1 2 6 17 18 19
  248  'SdFm-Ax 3 R V R'   1.1   7  10  -486.0ee -39.5   22.5  3 1 2 6 17 18 19ee
  249  'SdFm-Ax 4 L V L'   1.1   6  11  -556.0ee  39.5   22.5  3 1 2 6e   18 19ee
  250  'SdFm-Ax 4 R V R'   1.1   7  11  -556.0ee -39.5   22.5e 3 1 2 6 17 18 19ee
! Trail Truck Wheel/rail connections
  251  'Ax 3 Lt Wh/Rail'    4   10      -486.0ee  29.75    0.0    3
  252  'Ax 3 Rt Wh/Rail'    4   10      -486.0ee -29.75ee  0.0    3
  253  'Ax 4 Lt Wh/Rail'    4   11      -556.0ee  29.75ee  0.0    4
  254  'Ax 4 Rt Wh/Rail'    4   11      -556.0ee -29.75ee  0.0    4
  255  'Dummy Ctr Plt 2'   1.1   1   3  -521.0ee 0.0   22.7   3 4 5 6 20 20 20e

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).

 Paire#  Stiffness & Damping  F/S-extn.  F/S-comp.    K/D-parameters
---------------------------------------------------------------------------
\CHARACTERISTIC DATA
! ************************** Couplers ************************************
  1    1            0        1.0E09ee    -1.0E09ee
! Tow Rope
  2    2            3        1.0E09      -1.0E09
! ********************** Center Platee************************************ee
! Center plate longitudinal and lateral rim friction
  3    4    0     1.0        -1.0      0.0     1.0E06  1.0E03  0.5
! Centerplate vertical with longitudinal and lateral surface friction
!
! Cwe= 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 areee
! 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.ee
! Center Plate Lube 0.1  2/3*.1ee 0.0666e
! Center Plate Lube 0.2  2/3*.2 = 0.1333ee
! Center Plate Lube 0.3  2/3*.3ee 0.2000e
! Center Plate Lube 0.4  2/3*.4ee 0.2666e
! Center Plate Lube 0.5  2/3*.5 = 0.3333ee
!   4    5            0        1.0E06  1.0E03 0.0666
!   4    5            0        1.0E06  1.0E03 0.3333
    4    5            0        1.0E06  1.0E03 0.2666
! Centerplate damping, type 1.2 connection
```

```
!
! ********************** Roller Side Bearings0********************************00
! 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 **********************00
!  7   9          10       3.0        -3.0      0.0      1.0E06  1.0E03 0.3
! ********************** Bolster to Side Frame Connections0******************00
! Longitudinal
   8   11         12       1.0E09     -1.0E09
! Pitch stiffness and stops
   9   13         0         1.0E09     -1.0E09
! Warp/torsion
  10   14         0        1.0E09     -1.0E09
! Lateral stiffness and stops
  11   15         0         1.0E09     -1.0E09
! Vertical Springs
  12   16         0        0.0        -1.0E09
! Dummy roll characteristic for type 1.3 connection
  13    0         0        0.0        -1.0E09
! # 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        37.5   2.898E3  1.0E04  0.40   0.40   .T.
! 0.50 inch wedge rise (1.8393 - 0.50 = 1.3393 *01979 = 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.
!
!****************** Bearing Adapter Side Frame to Axle0********************00
! Vertical side frame to axle connections with friction, type 6.5
   15   18        0        1.0E06     1.0E03  0.5
! Vertical damping for bearing adapters with gap element
   16   0         19       1000.0     0.031382
! Longitudinal stiffness and stops
   17   20        0        1.0E09     -1.0E0900
! Lateral stiffness and stops
   18   21        0        1.0E09     -1.0E0900
! Yaw stiffness and stops
   19   22        0        1.0E09     -1.0E0900
! Dummy Center Plate Roll/Pitch/Yaw Connection
   20   0         0        1.0E09     -1.0E0900
```

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
!    1.E5  1.E2    2.5E5  2.5E2
\WHEEL/RAIL ELEMENT TIE
    1.E5  1.E2ee  1.E5ee 1.E2ee  2.5E5  2.5E2
     1ee      18.0      .F.        0        0
     2ee      18.0      .F.        0        0
     3ee      18.0      .F.        0        0
     4ee      18.0      .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
! *************************eCouplerse*********************************e
! Coupler to Ground Lead and Trail Ends
   1      2     0.0      1.0E1
                0.0      1.0
! Tow Rope to Ground Through C.G.
! 1500 LB/IN
   2      2     0.0      1.5E3
                0.0      1.0
   3      2     0.0      1.5E2ee
                0.0      1.0
! ********************* Center plate Connectionsee***************************
! Longitudinal and lateral rim normal stiffness
! Steel on steel, with 80 lb/in  +/-0.125 inch gap
   4      4    -1.101E3   -10.0   0.0  0.0
                 -0.126ee -0.125  0.0  1.0ee
! 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
   5      3     -3.0443E4ee  0.0             0.0
                 0.0         3.0443E-3       1.0
! Damping of center plate
   6      2      0.0      1.0E3
                 0.0      1.0
!                                            ********************************
! Lift off spring for side bearings
  7      3     -1.0E6ee  0.0        0.0
               -1.0ee    0.0        1.0
! Damping of side bearings
  8      2      0.0      0.0E0
                0.0      1.0
! ********************* Constant Contact Side Bearings *********************
! CCSB Pre-Loads
! Not Real Characteristics all are for just a quasi-static curve analysis
!
! 1000
!  9 7  -1.004E6 -3875ee-2125ee  -1000ee      0        0        0
!       -1.25ee -0.25ee -0.125ee     0     0.25    0.375        1
! 2000
```

```
!  9 7  -1.005E6 -5125  -3250    -2000     -500        0       0
!       -1.25   -0.25   -0.125       0     0.25    0.375       1
! 3000
!       -1.006E6 -6375  -4375    -3000    -1250   -687.5       0
!       -1.25   -0.25   -0.125       0     0.25    0.375       1
! 4000
!  9 7  -1.008E6 -7625    -5500  -4000    -2000    -1250       0
!       -1.25   -0.25   -0.125       0     0.25    0.375       1
! 5000
!       -1.009E6 -8875   -6625   -5000    -2750    -1875       0
!       -1.25   -0.25   -0.125       0     0.25    0.375       1
. 6000
!       -1.010E6 -10125          -6000    -3500    -2500       0
!       -1.25   -0.25   -0.125       0     0.25    0.375       1
! 7000
!       -1.010E6 -11375  -8875   -7000    -4250    -3125       0
!        -1.25   -0.25   -0.125      0     0.25    0.375       1
! 8000
!       -1.013E6 -12625  -10000   -8000    -5000    -3750      0
!       -1.25    -0.25   -0.125      0     0.25    0.375       1
! 9000
!  9 7  -1.014E6 -13875  -11125   -9000    -5750    -4375      0
!       -1.25   -0.25   -0.125       0     0.25    0.375       1
! 10000
!  9 7  -1.016E6 -15125 -12250   -10000    -6500    -5000      0
!       -1.25   -0.25   -0.125       0     0.25    0.375       1
! CCSB Damping
! 10  3  0.0   1000   1000
!        0.0   0.05   1.0
! ********************** Bolster to Side Frame Connections *******************
! Longitudinal
   11     2      0.0      1.E6
                 0.0      1.0
   12     2      0.0      1.E3
                 0.0      1.0
! Pitch Stiffness and Stops Mid Tolerance is Approx +/- 2.4 Degrees=0.042mRad
   13      3      0.0      0.0    6.40E7
                 0.0      0.042  1.042
! ****************** 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      0.0      2.55E05   8.95E05
                 0.0      0.030     0.040
! 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
! Lateral Stiffness of bolster to side frame connection divided by 4
   15     3      0.0      2.225E3   1.09E5
                 0.0      0.50      0.60
! Vertical Secondary Suspension
! 9-D5 outers and 5-D5 inners
!   16      5     -1.954E5 -9.5414E4  -3.50E2    0.0      0.0
!                 -3.7875  -3.6875     0.0       0.0625   1.0
! stiffness divided by 4
!   16      5     -0.4885E5 -2.38535E4 -8.75E1    0.0      0.0
!                 -3.7875  -3.6875      0.0       0.0625   1.0
! with initial offsets calculated for loaded static weight of -15403.78
  16      6     -0.4885E5 -2.38535E4  -1.540378E4 -8.75E1   0.0      0.0
                -1.39747  -1.29747     0.0          2.3900   2.4525   4.0
```

```
!
!
!  16      6      -4.48E+04 -1.98E+04e  -1.22E+04e  -1.23E+02 0.0ee    0.0
!                 -1.5171ee -1.4171ee    0.0         2.2704   2.3329   3.2079
!
!***********Optional control coils for a variably damped truck***************

!  17      6      -5.91E+04 -9.14E+03   -6.39E+03ee -1.81E+02 0.0ee    0.0
!                 -1.5171ee -1.4171ee    0.0         3.2079ee 3.5204   4.5204
!
!******************* Bearing Adapter Side Frame to Axlee********************
! Vertical Bearing adapter connection with offset for static load
   18      3      -1.5691E4 0.0ee       0.0
                   0.0ee    0.031382    1.0
! Vertical Bearing adapter damping
   19      2       0.0      1.E3ee
                   0.0      1.0
! Bearing adapter stops
! Longitudinal Stiffness with Stops
   20      3       0.0      1.0     1.E3
                   0.0      0.0468  0.0478
! Lateral Stiffness with Stops
   21      3       0.0      1.0     1.E3
                   0.0      0.250   0.251
! Yaw Stiffness with Stops
   22      3       0.0      0.0    6.4E5ee
                   0.0      0.030  0.040ee
```

```
 System file (.SYS) for NUCARS Version 2.3
==============================================

 \SYSTEM TITLE
 Loaded MAXI-STACK III 48' 5-UNIT WELL CAR

  Body #   '3315 Char Name33'          C.G. Posn in X, Y, & Z33
             No. & DoF List33          Mass, Roll, Pitch, & Yaw Inertia33
 -----------------------------------------------------------------------------
 \BODY DATA

 ! Platforms
 ! Loaded
      1     '     Unit B     '     -381.7533   0.0        105.83
         6   1 2 3 4 5 6            388.505233 3.2197E+06      1.5946E+07
         1.4856E+0733
      2     '     Unit C     '    -1075.7533   0.0        105.83
         6   1 2 3 4 5 6            377.357533 3.0091E+06      1.5233E+07
         1.4144E+07
      3     '     Unit D     '    -1769.7533   0.0        105.83
         6   1 2 3 4 5 6            377.357533 3.0091E+06      1.5233E+07
         1.4144E+07
      4     '     Unit E     '    -2463.7533   0.0        105.83
         6   1 2 3 4 5 6            377.357533 3.0091E+06      1.5233E+07
         1.4144E+0733
      5     '     Unit A     '    -3158.12533  0.0        105.83
         6   1 2 3 4 5 6            388.505233 3.2197E+06      1.5946E+07
         1.34856E+0733
 ! Truck B
     11    '33Bolster B33    '            -34.033      0.0       14.0
         6  1 2 3 4 5 6          3.47     2.53E0333 1.1E03    2.53E03
     12    ' Lft SF Trk B    '            -34.033     39.0       16.5
         6  1 2 3 4 5 6          2.73     1.02E0333 1.26E033  1.26E03
     13    '33Rgt SF Trk B   '            -34.033    -39.033     16.5
         6  1 2 3 4 5 6          2.73     1.02E0333 1.26E0333 1.26E0333
     14    '33Axle number 1 '              0.0        0.0       16.5
         5  1  2  3  4  6        7.09     5.40E03   2.29E03   5.40E03
     15    '33Axle number 2 '             -68.033     0.0       16.5
         5  1  2  3  4  6        7.09     5.40E0333 2.29E03   5.40E03
 ! Truck C
     21    '33Bolster C      '          -728.7533    0.0       16.0
         6  1 2 3 4 5 6          4.0      2.53E03   1.1E0333  2.53E03
     22    '33Lft SF Trk C   '          -728.7533   39.5       19.0
         6  1 2 3 4 5 6          3.2      1.08E0333 1.33E0333 1.33E0333
           ' Rgt SF Trk C    '          -728.7533  -39.533     19.0
         6  1 2 3 4 5 6          3.2      1.08E0333 1.33E0333 1.33E033
     24    '33Axle number 3 '           -692.7533    0.0       19.0
         5  1  2  3  4  6        8.0      5.40E03   2.29E03   5.40E03
     25    '33Axle number 4 '           -764.7533    0.0       19.0
         5  1  2  3  4  6        8.0      5.40E03   2.29E03   5.40E03
 ! Truck D
     31    ' Bolster D       '         -1422.7533    0.0       16.0
         6  1 2 3 4 5 6          4.0      2.53E03   1.1E03    2.53E03
           '33Lft SF Trk D   '         -1422.7533   39.5       19.03
         6  1 2 3 4 5 6          3.2      1.08E0333 1.33E03   1.33E03
           '33Rgt SF Trk D   '         -1422.7533  -39.533     19.0
         6  1 2 3 4 5 6          3.2      1.08E03   1.33E0333 1.33E0333
           '3 Axle number 5 '          -1386.7533    0.0       19.0
         5  1  2  3  4  6        8.0      5.40E03   2.29E03   5.40E03
           '33Axle number 6 ' 3 3      -1458.7533    0.0       19.0
         5  1  2  3  4  6        8.0      5.40E03   2.29E03   5.40E03
 ! Truck E
     41    '33Bolster E      '         -2116.7533    0.0       16.0
         6  1 2 3 4 5 6          4.0      2.53E03   1.1E0333  2.53E03
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     42   ' Lft SF Trk E  '          -2116.75    39.5        19.0
        6  1 2 3 4 5 6        3.2     1.08E03   1.33E03   1.33E03
     43   ' Rgt SF Trk E  '          -2116.75   -39.5        19.0
        6  1 2 3 4 5 6        3.2     1.08E03   1.33E03   1.33E03
          ' Axle number 7 '          -2080.75    0.0         19.0
        5  1  2  3  4  6      8.0     5.40E03   2.29E03   5.40E03
          ' Axle number 8 '          -2152.75    0.0         19.0
        5  1  2  3  4  6      8.0     5.40E03   2.29E03   5.40E03
! Truck F
     51   ' Bolster F     '          -2810.75    0.0         16.0
        6  1 2 3 4 5 6        4.0     2.53E03   1.1E03    2.53E03
     52   ' Lft SF Trk F  '          -2810.75                19.0
        6  1 2 3 4 5 6        3.2     1.08E03   1.33E03   1.33E03
     53   ' Rgt SF Trk F  '          -2810.75   -39.5        19.0
        6  1 2 3 4 5 6        3.2     1.08E03   1.33E03   1.33E03
          ' Axle number 9 '          -2774.75    0.0         19.0
        5  1  2  3  4  6      8.0     5.40E03   2.29E03   5.40E03
          ' Axle number10 '          -2846.75    0.0         19.0
        5  1  2  3  4  6      8.0     5.40E03   2.29E03   5.40E03
! Truck A
     61   ' Bolster A     '          -3505.5     0.0         14.0
        6  1 2 3 4 5 6        3.47    2.53E03   1.1E03    2.53E03
     62   ' Lft SF Trk A  '          -3505.5    39.0         16.5
        6  1 2 3 4 5 6        2.73    1.02E03   1.26E03   1.26E03
     63   ' Rgt SF Trk A  '          -3505.5   -39.0         16.5
        6  1 2 3 4 5 6        2.73    1.02E03   1.26E03   1.26E03
     64   ' Axle number11 '          -3471.5     0.0         16.5
        5  1  2  3  4  6      7.09    5.40E03   2.29E03   5.40E03
     65   ' Axle number12 '          -3539.5     0.0         16.5
        5  1  2  3  4  6      7.09    5.40E03   2.29E03   5.40E03


\CONNECTION DATA
  387
! General Connections
! Tow Spring
    1  'Tow Spring     '   1   0   1  -381.375 0.0  105.83  1  1
! Articulated Connector
!     2  'Artic. Conn. 1.'  1.1  1   2  -728.75 0.0   32.0   3  1 2 3  2 3 4
!     3  'Artic. Conn. 2.'  1.1  2   3 -1422.75 0.0   32.0   3  1 2 3  2 3 4
!     4  'Artic. Conn. 3.'  1.1  3   4 -2116.75 0.0   32.0   3  1 2 3  2 3 4
!     5  'Artic. Conn.   '  1.1  4   5 -2810.75 0.0   32.0   3  1 2 3  2 3 4
! Articulated Connector
!   2  'Artic. Conn. 1.'  1.3  1   2  -728.75  0.0   32.0   6  1 2 3 4 5 6  2
3 5 9 9 9
!   3  'Artic. Conn. 2.'  1.3  2   3 -1422.75  0.0   32.0   6  1 2 3 4 5 6  2
3 6 9 9 9
!   4  'Artic. Conn.   '  1.3  3   4 -2116.75  0.0   32.0   6  1 2 3 4 5 6
3 7 9 9 9
!   5  'Artic. Conn. 4.'  1.3  4   5 -2810.75  0.0   32.0   6  1 2 3 4 5 6  2
3 8 9 9 9
! Articulated Connector
    2  'Artic. Conn. 1.'  1.3  1   2  -728.75  0.0   32.0   6  1 2 3 4 5 6  2
    3 9 9 9 9
    3  'Artic. Conn. 2.'  1.3  2   3 -1422.75  0.0   32.0   6  1 2 3 4 5 6  2
    3 9 9 9 9
       'Artic. Conn. 3.'       3   4 -2116.75  0.0   32.0   6  1 2 3 4 5 6
    3 9 9 9 9
       'Artic. Conn. 4.'  1.3  4   5 -2810.75  0.0   32.0   6  1 2 3 4 5 6
    3 9 9 9 9
! 5 + 0 = 5
! Truck 1 or Truck B
! Lead Truck Lateral and longitudinal connections for 14" center plate using
! 6.2 line friction element for rim friction at four corners
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  101   'Ld CB-B  LgY LL'   6.2  11   1    -34.0     7.0    23.0   2 1   100
  102   'Ld CB-B  LgY LR'   6.2   1  11    -34.0    -7.0    23.0   2 1   100
  103   'Ld CB-B  LtX Fr'   6.2  11   1    -27.0     0.0    23.0   1 2   101
  104   'Ld CB-B  LtX Tr'   6.2   1  11    -41.0     0.0    23.0   1 2   101
! Center Plate Rim Damping
  105   'Ld CB-B  LgY LL'   1.2  11   1    -34.0     7.0    23.0   2    102
  106   'Ld CB-B  LgY LR'   1.2   1  11    -34.0    -7.0    23.0   2    102
  107   'Ld CB-B  LtX Fr'   1.2  11   1    -27.0     0.0    23.0   1    102
  108   'Ld CB-B  LtX Tr'   1.2   1  11    -41.0     0.0    23.0   1    102
! Long./lat. car body center plate to bolster connections
! 109  'BolB-Pltl L/L  '  1.1  1  11   -34.0  0.0   23.0    2  1 2  X Y
! Vertical/Yaw for center plates line friction element
  109  'BolB Lft CP Con'  6.2  1  11   -34.0   7.0  23.0  3  1  103
  110  'BolB Rgt CP Con'  6.2  1  11   -34.0  -7.0  23.0  3  1  103
  111  'BolB Fr  CP Con'  6.2  1  11   -27.0   0.0  23.0  3  2  103
  112  'BolB Tr  CP Con'  6.2  1  11   -41.0   0.0  23.0  3  2  103
! Vertical centerplate connection damping
  113  'BolB Lf CP Damp'   1   1  11   -34.0   7.0  23.0  3  104
  114  'BolB Rt CP Damp'   1   1  11   -34.0  -7.0  23.0  3  104
  115  'BolB Fr CP Damp'   1   1  11   -27.0   0.0  23.0  3  104
  116  'BolB Tr CP Damp'   1   1  11   -41.0   0.0  23.0  3  104
! Vertical 105 left blank for articulated trucks
! Constant Contact Side Bearings
  117  'BolB-CB Lft SB '  6.2  1  11   -34.000   25.000  27.0  3  1  106
  118  'BolB-CB Rgt SB '  6.2  1  11   -34.000  -25.000  27.0  3  1  106
! Constant Contact Side Bearings Rollers
  119  'BolB-CB Lft Gap'  1.2  1  11   -34.000   25.000  27.0  3  107
  120  'BolB-CB Rgt Gap'  1.2  1  11   -34.000  -25.000  27.0  3  107
! Bolster to side frame longitudinal,lateral and yaw connections
  121  '   BolB-SF M Lft'  1.1 11  12   -34.0   39.0  14.0  4  1 2 5 6 108 109
  110 111
  122  '   BolB-SF M Rgt'  1.1 11  13   -34.0  -39.0  14.0  4  1 2 5 6 108 109
  110 111
! 4-Vertical/Pitch bolster to side frame connections +/- 3.75
  123 'B1 Ld Bol-SF Lft'   1  11  12   -30.25  35.25 14.0  3  112
  124 'B1 Ld Bol-SF Rgt'   1  11  13   -30.25 -35.25 14.0  3  112
  125 'B1 Ld Bol-SF Lft'   1  11  12   -30.25  42.75 14.0  3  112
  126 'B1 Ld Bol-SF Rgt'   1  11  13   -30.25 -42.75 14.0  3  112
  127 'B1 Tr Bol-SF Lft'   1  11  12   -37.75  35.25 14.0  3  112
  128 'B1 Tr Bol-SF Rgt'   1  11  13   -37.75 -35.25 14.0  3  112
  129 'B1 Tr Bol-SF Rgt'   1  11  12   -37.75  42.75 14.0  3  112
  130 'B1 Tr Bol-SF Lft'   1  11  13   -37.75 -42.75 14.0  3  112
! 2D Friction wedge connection Between bolster and side frame
  131 '  BolB-SF LL Wg'   6.7 11  12   -25.5   39.0  14.5  3  2  113
  132 '  BolB-SF LR Wg'   6.7 11  13   -25.5  -39.0  14.5  3  2  113
  133 '  BolB-SF LL Wg'   6.7 11  12   -42.5   39.0  14.5  3  2  113
  134 '  BolB-SF LR Wg'   6.7 11  13   -42.5  -39.0  14.5  3  2  113
! Side frame to axle longitudinal, lateral, and yaw stops
  135 'TrkBLSF-LdAX M '   1.1 12  14     0.0   39.0  22.0  3  1 2 6  114 116
  118
  136 'TrkBLSF-TrAX M '   1.1 12        -68.0   39.0  22.0  3  1 2 6  114 116

  137 'TrkBRSF-LdAX M '   1.1 13  14     0.0  -39.0  22.0  3  1 2 6  115 117
  119
  138 'TrkBRSF-TrAX M '   1.1 13  15   -68.0  -39.0  22.0  3  1 2 6  115 117
  119
! Verical surface friction element for side frame to axle connection elements
! are placed +/- 3.0 inches apart to react roll, and pitch if the side frame

  139 'SdFm-Ax 1 L V L'   6.5  12  14     0.0   42.0  24.0  3 1 2  120
  140 'SdFm-Ax 1 L V R'   6.5  12  14     0.0   36.0  24.0  3 1 2  120
  141 'SdFm-Ax 1 R V R'        13  14     0.0  -42.0  24.0  3 1 2  120
  142 'SdFm-Ax 1 R V L'   6.5  13  14     0.0  -36.0  24.0  3 1 2  120
  143 'SdFm-Ax 2 L V L'   6.5  12        -68.0   42.0  24.0  3 1 2  120
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!
!
!
!
!
!
!                                             -53.252239.0226.50  12  122
! 5+ 54 = 59 connections Truck
! 2 or Truck C
! Truck Lateral and longitudinal connections for 16" center plate using
! 6.2 line friction element for rim friction at four corners
  201   'Ld CB-C  LgY LL'   6.2  21   1   -728.7522  8.0     23.0   2 1 200
  202   'Ld CB-C  LgY LR'   6.2   1  21   -728.7522 -8.022   23.0   2 1 200
  203   'Ld CB-C  LtX Fr'   6.2  21   1   -720.7522  0.022   23.0   1 2 201
  204   'Ld CB-C  LtX Tr'   6.2   1  21   -736.7522  0.022   23.0   1 2 201
! Center Plate Rim Damping
  205   'Ld CB-C  LgY LL'   1.22221   1   -728.7522  8.0     23.0   2   202
  206   'Ld CB-C  LgY LR'   1.2   1  21   -728.7522 -8.022   23.0   2   202
  207   'Ld CB-C  LtX Fr'   1.2  21   1   -720.7522  0.022   23.0   1   202
  208   'Ld CB-C  LtX Tr'   1.222 1  21   -736.7522  0.0     23.0   1   202
! Long./lat. car body center plate to bolster connections
! 209   'BolC-Plt1 L/L  '  1.1  1  21  -728.75   0.022 25.062  2  1 2  X Y
! Vertical/Yaw for center plates line friction element
  209  'BolC Lft CP Con'  6.2  1  2   -728.7522 8.0  27.0  3  1  2032
  210  'BolC Rgt CP Con'  6.2  1  2   -728.75  -8.0  27.0  3  1  20322
  211  'BolC Fr  CP Con'  6.2  1  2   -720.7522 0.0  27.0  3  2  2032
  212  'BolC Tr  CP Con'  6.2  1  2   -736.7522 0.0  27.0  3  2  2032
! Vertical centerplate connection damping
  213  'BolC Lf CP Damp'   1   1  2   -728.7522 8.0  27.0  3  2042
  214  'BolC Rt CP Damp'   1   1  2   -728.75  -8.0  27.0  3  20422
  215  'BolC Fr CP Damp'   1   1  2   -720.7522 0.0  27.0  3  2042
  216  'BolC Tr CP Damp'   1   1  2   -736.7522 0.0  27.0  3  2042
! Vertical/Yaw for center plates line friction element
  217  'BolC Lft CP Con'  6.2  2  21  -728.7522 8.0  23.0  3  1  2052
  218  'BolC Rgt CP Con'  6.2  2  21  -728.75  -8.0  23.0  3  1  20522
  219  'BolC Fr  CP Con'  6.2  2  21  -720.7522 0.0  23.0  3  2  2052
  220  'BolC Tr  CP Con'  6.2  2  21  -736.7522 0.0  23.0  3  2  2052
! Vertical centerplate connection damping
  221  'BolC Lf CP Damp'   1   2  21  -728.7522 8.0  23.0  3  2042
  222  'BolC Rt CP Damp'   1   2  21  -728.75  -8.0  23.0  3  20422
  223  'BolC Fr CP Damp'   1   2  21  -720.7522 0.0  23.0  3  2042
  224  'BolC Tr CP Damp'   1   2  21  -736.7522 0.0  23.0  3  2042
! Constant Contact Side Bearings
  225  'BolC-CB Lft SB2'  6.2  1  21  -714.25022 25.000  38.0  3  1  2062
  226  'BolC-CB Rgt SB22  6.2  1  21  -714.250  -25.000  38.0  3  1  20622
  227  'BolC-CC Lft SB22  6.2  2  21  -743.25022 25.000  38.0  3  1  2062
  228  'BolC-CC Rgt SB '  6.2  2  21  -743.250  -25.000  38.0  3  1  20622
! Constant Contact Side Bearings Rollers
  229  'BolC-CB Lft Gap'  1.2  1  21  -714.25022 25.000  38.0  3  2072
  230  'BolC-CB Rgt Gap'  1.2  1  21  -714.250  -25.000  38.0  3  20722
  231  'BolC-CC Lft Gap'  1.2  2  21  -743.25022 25.000  38.0  3  2072
  232  'BolC-CC Rgt Gap'  1.2  2  21  -743.250  -25.000  38.0  3  20722
! Bolster to side frame longitudinal,lateral and yaw connections
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  233  '  BolC-SF M Lft'  1.1 21  22  -728.75   39.5  14.5  4  1 2 5 6 208 209
  210 211
  234  '  BolC-SF M Rgt'  1.1 21  23  -728.75          14.5  4  1 2 5 6 208 209
  210 211
! 4-Vertical/Pitch bolster to side frame connections +/- 3.75
  235 'B2 Ld Bol-SF Lft'   1  21  22  -725.00  35.75 14.5  3  212
  236 'B2 Ld Bol-SF Rgt'   1  21  23  -725.00 -35.75 14.5  3  212
  237 'B2 Ld Bol-SF Lft'   1  21  22  -725.00  43.25 14.5  3  212
  238 'B2 Ld Bol-SF Rgt'   1  21  23  -725.00 -43.25 14.5  3  212
  239 'B2 Tr Bol-SF Lft'   1  21  22  -732.50  35.75 14.5  3  212
  240 'B2 Tr Bol-SF Rgt'   1  21  23  -732.50 -35.75 14.5  3  212
  241 'B2 Tr Bol-SF Lft'   1  21  22  -732.50  43.25 14.5  3  212
  242 'B2 Tr Bol-SF Rgt'   1  21  23  -732.50 -43.25 14.5  3  212
! 2D Friction wedge connection between bolster and side frame
  243 '  BolC-SF LL Wg'   6.7 21  22  -720.25  39.5  14.5  3  2  213
  244 '  BolC-SF LR Wg'   6.7 21  23  -720.25 -39.5  14.5  3  2  213
  245 '  BolC-SF TL Wg'   6.7 21  22  -737.25  39.5  14.5  3  2  213
  246 '  BolC-SF TR Wg'   6.7 21  23  -737.25 -39.5  14.5  3  2  213
! Side frame to axle longitudinal, lateral, and yaw stops
  247 'TrkCLSF-LdAX M '   1.1 22  24  -692.75   39.5  21.5  3  1 2 6  214 216
  218
  248 'TrkCLSF-TrAX M '   1.1 22  25  -764.75   39.5  21.5  3  1 2 6  214 216
  218
  249 'TrkCRSF-LdAX M '   1.1 23  24  -692.75  -39.5  21.5  3  1 2 6  215 217
  219
  250 'TrkCRSF-TrAX M '   1.1 23  25  -764.75         21.5  3  1 2 6  215 217
  219
! Verical surface friction element for side frame to axle connection elements
! are placed +/- 3.0 inches apart to react roll, and pitch if the side frame
  251 'SdFm-Ax 3 L V L'   6.5  22  24  -692.75  42.5  25.5  3 1 2  220
  252 'SdFm-Ax 3 L V R'        22  24  -692.75  36.5  25.5  3 1 2  220
  253 'SdFm-Ax 3 R V R'   6.5  23  24  -692.75 -42.5  25.5  3 1 2  220
  254 'SdFm-Ax 3 R V L'   6.5  23  24  -692.75 -36.5  25.5  3 1 2  220
  255 'SdFm-Ax 4 L V L'   6.5  22  25  -764.75  42.5  25.5  3 1 2  220
  256 'SdFm-Ax 4 L V R'   6.5  22  25  -764.75  36.5  25.5  3 1 2  220
  257 'SdFm-Ax 4 R V R'   6.5      25  -764.75 -42.5  25.5  3 1 2  220
  258 'SdFm-Ax 4 R V L'   6.5  23  25  -764.75 -36.5  25.5  3 1 2  220
! Vertical side frame to axle connection damping
  259 'SdFm-Ax 3 L Vrt'   1  22  24  -692.75   39.5  25.5  3  221
  260 'SdFm-Ax 3 R Vrt'   1  23  24  -692.75  -39.5  25.5  3  221
  261 'SdFm-Ax 4 L Vrt'   1  22  25  -764.75   39.5  25.5  3  221
  262 'SdFm-Ax 4 R Vrt'   1  23  25  -764.75         25.5  3  221
! Wheel/rail connections
  263 'Ax 3 Lt Wh/Rail'   4   24     -692.75  29.75  0.0  3
  264 'Ax 3 Rt Wh/Rail'   4   24     -692.75 -29.75  0.0  3
  265 'Ax 4 Lt Wh/Rail'   4   25     -764.75  29.75  0.0  4
  266 'Ax 4 Rt Wh/Rail'   4   25     -764.75 -29.75  0.0  4
! Truck Frame Bracing
! 267 'TrCFrame Brace1'   -1  22 23  -738.75  39.5  6.50
!                                    -777.25 -39.5  6.50  1  222
! 268 'TrCFrame Brace2'   -1  23 22  -738.75 -39.5  6.50
!                                    -777.25  39.5  6.50  1  222
! 66 +59= 125 Connections
!
! Truck 3 or Truck D
! Truck Lateral and longitudinal connections for 16" center plate using
! 6.2 line friction element for rim friction at four corners
  301   'Ld CB-D  LgY LL'   6.2  31   3 -1422.75   8.0   23.0  2 1  300
  302   'Ld CB-D  LgY LR'   6.2   3  31 -1422.75  -8.0   23.0  2 1  300
  303   'Ld CB-D  LtX Fr'   6.2  31   3 -1414.75   0.0   23.0  1 2  301
  304   'Ld CB-D  LtX Tr'   6.2   3  31 -1430.75   0.0   23.0  1 2  301
! Center Plate Rim Damping
  305   'Ld CB-D  LgY LL'   1.2  31   3 -1422.75   8.0   23.0  2  302
  306   'Ld CB-D  LgY LR'   1.2   3  31 -1422.75  -8.0   23.0  2  302
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  307   'Ld CB-D  LtX Fr'   1.2  31   3 -1414.75    0.0    23.0   1  302
  308   'Ld CB-D  LtX Tr'   1.2   3  31 -1430.75    0.0    23.0   1  302
! Long./lat. car body center plate to bolster connections
! 309  'BolD-Plt2 L/L  '  1.1  2  31 -1422.75  0.0   23.0    2  1 2  5 6
! Vertical/Yaw for center plates line friction element
  309  'BolD Lft CP Con'  6.2  2  3  -1422.7533 8.0  27.03 3  1  303
  310  'BolD Rgt CP Con'  6.2  2  3  -1422.75  -8.0  27.0333  1  3033
  311  'BolD Fr  CP Con'  6.2  2  3  -1414.7533 0.0  27.0  3  2  3033
  312  'BolD Tr  CP Con'  6.2  2  3  -1430.7533 0.0  27.03 3  2  303
! Vertical centerplate connection damping
  313  'BolD Lf CP Damp'   1   2  3  -1422.7533 8.0  27.03 3  304
  314  'BolD Rt CP Damp'   1   2  3  -1422.7533-8.03327.03 3  304
  315  'BolD Fr CP Damp'   133 2  3  -1414.7533 0.03327.03 3  304
  316  'BolD Tr CP Damp'   1   2  3  -1430.7533 0.03327.03 3  304
! Vertical/Yaw for center plates line friction element
  317  'BolD Lft CP Con'  6.2  3  31 -1422.75   8.0  23.0  3  1  305
  318  'BolD Rgt CP Con'  6.2  3  31 -1422.75  -8.0  23.0333  1  3053
  319  'BolD Fr  CP Con'  6.2  3  31 -1414.75   0.0  23.0  3  2  305
  320  'BolD Tr  CP Con'  6.2  3  31 -1430.75   0.0  23.0  3  2  305
! Vertical centerplate connection damping
  321  'BolD Lf CP Damp'   1   3  31 -1422.75   8.0  23.0  3  304
  322  'BolD Rt CP Damp'   1   3  31 -1422.75  -8.03323.03 3  304
  323  'BolD Fr CP Damp'   1   3  31 -1414.75   0.03323.0  3  304
  324  'BolD Tr CP Damp'   1   3  31 -1430.75   0.03323.0  3  304
! Constant Contact Side Bearings
  325  'BolD-CC Lft SB3'  6.2  2  31 -1408.250   25.000  38.0  3  1  306
  326  'BolD-CC Rgt SB3'  6.2  2  31 -1408.250  -25.0003338.03 3  1  306
  327  'BolD-CD Lft SB3'  6.2  3  31 -1437.250   25.0003338.0  3  1  306
  328  'BolD-CD Rgt SB3'  6.2  3  31 -1437.250  -25.0003338.0  3  1  3063
! Constant Contact Side Bearings
  329  'BolD-CC Lft Gap'  1.2  2  31 -1408.250   25.000  38.0  3333073
  330  'BolD-CC Rgt Gap'  1.2  2  31 -1408.250  -25.000  38.0  3333073
  331  'BolD-CD Lft Gap'  1.2  3  31 -1437.250   25.000  38.0  3  307
  332  'BolD-CD Rgt Gap'  1.2  3  31 -1437.250  -25.000  38.0  3333073
! Bolster to side frame longitudinal,lateral and yaw connections
  333  '  BolD-SF M Lft'  1.1 31  32 -1422.75   39.5  14.5  4 1 2 5 6 308 309
  310 311
  334  '  BolD-SF M Rgt'  1.1 31  33 -1422.75  -39.5  14.5  4 1 2 5 6 308 30933
  310 311
! 4-Vertical/Pitch bolster to side frame connections3+/- 3.7533
  335 'B3 Ld Bol-SF Lft'  1  31  32 -1419.00  35.75 14.5  3  312
  336 'B3 Ld Bol-SF Rgt'  1  31  33 -1419.00 -35.75 14.5  3333123
  337 'B3 Ld Bol-SF Lft'  1  31  32 -1419.00  43.25 14.5  3  312
  338 'B3 Ld Bol-SF Rgt'  1  31  33 -1419.00 -43.25 14.5  3333123
  339 'B3 Tr Bol-SF Lft'  1  31  32 -1426.50  35.75 14.5  3  312
  340 'B3 Tr Bol-SF Rgt'  1  31  33 -1426.50 -35.75 14.5  3333123
  341 'B3 Tr Bol-SF Lft'  1  31  32 -1426.50  43.25 14.5  3  312
  342 'B3 Tr Bol-SF Rgt'  1  31  33 -1426.50 -43.25 14.5  3  312
! 2D Friction wedge connection Between bolster and side frame
  3433'  BolD-SF TL Wg'   6.7 31  32 -1414.25  39.5  14.5  3  2  313
  344 '  BolD-SF TR Wg'   6.7 31  33 -1414.25 -39.5  14.5  33323 313
  345 '  BolD-SF TL Wg'   6.7 31  32 -1431.25  39.5  14.5  3  2  313
  3463'  BolD-SF TR Wg'   6.7 31  33 -1431.25 -39.5  14.5  3332  313
! Side frame to axle longitudinal, lateral, and yaw stops
  347 'TrkDLSF-LdAX M '   1.1 32  34 -1386.75   39.5  21.5  3  1 2 6  314 316
  318
  348 'TrkDLSF-TrAX M ' 3 B.1 32  35 -1458.75   39.5  21.5  3  1 2 6  314 316
  318
  349 'TrkDRSF-LdAX M '   1.1 33  34 -1386.75  -39.53321.5  3  1 2 6  315 3173
  319
  350 'TrkDRSF-TrAX M ' 3 B.1 33  35 -1458.75  -39.53321.5  3  1 2 6  315 317
  319
! Verical surface friction element for side frame to axle connection elements
! are placed +/- 3.0 inches apart to react roll, and pitch if the side frame
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  352 'SdFm-Ax 5 L V R'   6.5  32  34 -1386.75   36.5  25.5  3 1 2  320
  353 'SdFm-Ax 5 R V R'   6.5      34 -1386.75  -42.5  25.5  3 1 2  320
  354 'SdFm-Ax 5 R V      6.5         -1386.75  -36.5  25.5  3 1 2  320
  355 'SdFm-Ax 6 L V L'   6.5  32     -1458.75   42.5  25.5  3 1 2  320
  356 'SdFm-Ax 6 L V R'   6.5  32     -1458.75   36.5  25.5  3 1 2  320
  357 'SdFm-Ax 6 R V R'   6.5  33     -1458.75  -42.5  25.5  3 1 2  320
  358 'SdFm-Ax 6 R V L'   6.5  33     -1458.75  -36.5  25.5  3 1 2  320
! Vertical side frame to axle connection damping
      'SdFm-Ax 5 L Vrt'   1  32  34 -1386.75   39.5  25.5  3  321
  360 'SdFm-Ax 5 R Vrt'   1      34 -1386.75  -39.5  25.5  3  321
  361 'SdFm-Ax 6 L Vrt'   1  32  35 -1458.75   39.5  25.5  3  321
  362 'SdFm-Ax 6 R Vrt'   1      35 -1458.75  -39.5  25.5  3  321
! Wheel/rail connections
  363 'Ax 5 Lt Wh/Rail'   4   34    -1386.75   29.75  0.0  5
  364 'Ax 5 Rt Wh/Rail'   4   34    -1386.75  -29.75  0.0  5
  365 'Ax 6 Lt Wh/Rail'   4   35    -1458.75   29.75  0.0  6
  366 'Ax 6 Rt Wh/Rail'   4         -1458.75  -29.75  0.0  6
! Truck Frame Bracing
!     'TrDFrame Brace1'   -1  32 33 -1488.75  39.5  6.50
!                                   -1527.25 -39.5  6.50  1  322
! 368 'TrDFrame Brace2'         32 -1488.75 -39.5  6.50
!                                   -1527.25        6.50  1  322
! 66 + 125= 191 Connections
!
! Truck 4 or Truck E
! Truck Lateral and longitudinal connections for 16" center plate using
! 6.2 line friction element for rim friction at four corners
 401   'Ld CB-E  LgY LL'   6.2       4 -2116.75    8.0    23.0   2 1   400
 402   'Ld CB-E  LgY LR'   6.2   4  41 -2116.75   -8.0    23.0   2 1   400
 403   'Ld CB-E  LtX Fr'   6.2  41   4 -2108.75    0.0    23.0   1 2   401
 404   'Ld CB-E  LtX Tr'   6.2   4  41 -2124.75    0.0    23.0   1 2   401
! Center Plate Rim Damping
 405   'Ld CB-E  LgY LL'   1.2  41   4 -2116.75    8.0    23.0   2  402
 406   'Ld CB-E  LgY LR'   1.2   4  41 -2116.75   -8.0    23.0   2  402
 407   'Ld CB-E  LtX Fr'   1.2  41   4 -2108.75    0.0    23.0   1  402
 408   'Ld CB-E  LtX Tr'   1.2   4  41 -2124.75    0.0    23.0   1  402
! Long./lat. car body center plate to bolster connections
! 409  'BolE-Plt3 L/L  '  1.1  3  41 -2116.75  0.0   23.0    2  1 2  5 6
! Vertical/Yaw for center plates line friction element
 409   'BolE Lft CP Con'  6.2  3  4  -2116.75   8.0  27.0  3  1  403
 410   'BolE Rgt CP Con'  6.2  3  4  -2116.75  -8.0  27.0  3  1  403
 411   'BolE Fr  CP Con'  6.2  3  4  -2108.75   0.0  27.0  3  2  403
 412   'BolE Tr  CP Con'  6.2  3  4  -2124.75   0.0  27.0  3  2  403
! Vertical centerplate connection damping
 413   'BolE Lf CP Damp'  1   3  4  -2116.75   8.0  27.0  3
 414   'BolE Rt CP Damp'  1   3  4  -2116.75  -8.0  27.0  3  404
 415   'BolE Fr CP Damp'  1   3  4  -2108.75   0.0  27.0  3  404
 416   'BolE Tr CP Damp'  1   3  4  -2124.75   0.0  27.0  3  404
! Vertical/Yaw for center plates line friction element
 417   'BolE Lft CP Con'  6.2  4  41 -2116.75   8.0  23.0  3  1  405
 418   'BolE Rgt CP Con'  6.2  4  41 -2116.75  -8.0  23.0  3  1  405
 419   'BolE Fr  CP Con'  6.2  4  41 -2108.75   0.0  23.0  3  2  405
 420   'BolE Tr  CP Con'  6.2  4  41 -2124.75   0.0  23.0  3  2  405
! Vertical centerplate connection damping
 421   'BolE Lf CP Damp'  1   4  41 -2116.75   8.0  23.0  3  404
 422   'BolE Rt CP Damp'  1   4  41 -2116.75  -8.0  23.0  3  404
 423   'BolE Fr CP Damp'  1   4  41 -2108.75   0.0  23.0  3  404
 424   'BolE Tr CP Damp'  1   4  41 -2124.75   0.0  23.0  3  404
! Constant Contact Side Bearings
 425   'BolE-CD Lft SB '  6.2  3  41 -2102.250   25.000  38.0  3  1  406
 426   'BolE-CD Rgt SB '  6.2  3  41 -2102.250  -25.000  38.0  3  1  406
 427   'BolE-CE Lft SB '  6.2  4  41 -2131.250   25.000  38.0  3  1  406
 428   'BolE-CE Rgt SB '  6.2  4  41 -2131.250  -25.000  38.0  3  1  406
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! Constant Contact Side Bearings
  429  'BolE-CD Lft Gap'  1.2  3  41 -2102.250   25.000  38.0  3  407
  430  'BolE-CD Rgt Gap'  1.2  3  41 -2102.250  -25.000  38.0  3  407
  431  'BolE-CE Lft Gap'  1.2  4  41 -2131.250   25.000  38.0  3  407
  432  'BolE-CE Rgt Gap'  1.2  4  41 -2131.250  -25.000  38.0  3  407
! Bolster to side frame longitudinal,lateral and yaw connections
  433  '   BolE-SF M Lft'  1.1 41  42 -2116.75        14.5  4  1 2 5 6 408 409
  410 411
  434  '   BolE-SF M Rgt'  1.1 41  43 -2116.75  -39.5  14.5  4  1 2 5 6 408 409
  410 411
! 4-Vertical/Pitch bolster to side frame connections +/- 6.0
         Ld Bol-SF Lft'   1  41  42 -2113.00  35.75 14.5  3  412
  436 'B4 Ld Bol-SF Rgt'   1  41  43 -2113.00 -35.75 14.5  3  412
      'B4 Ld Bol-SF Lft'   1  41  42 -2113.00  43.25 14.5  3  412
  438    Ld Bol-SF Rgt'   1  41  43 -2113.00 -43.25 14.5  3  412
  439    Tr Bol-SF Lft'   1  41  42 -2120.50  35.75 14.5  3  412
  440 'B4 Tr Bol-SF Rgt'   1  41  43 -2120.50 -35.75 14.5  3  412
  441    Tr Bol-SF Lft'   1  41  42 -2120.50  43.25 14.5  3  412
  442 'B4 Tr Bol-SF Rgt'   1  41  43 -2120.50 -43.25 14.5  3  412
! 2D Friction wedge connection Between bolster and side frame
      '  BolE-SF LL Wg'   6.7 41  42 -2108.25  39.5  14.5  3  2  413
  444 '  BolE-SF LR Wg'   6.7 41  43 -2108.25 -39.5  14.5  3  2  413
      '  BolE-SF TL Wg'   6.7 41  42 -2125.25  39.5  14.5  3  2  413
  446 '  BolE-SF TR Wg'   6.7 41  43 -2125.25 -39.5  14.5  3  2  413
! Side frame to axle longitudinal, lateral, and yaw stops
      'TrkELSF-LdAX M '   1.1 42  44 -2080.75        21.5  3  1 2 6  414 416
  418
  448 'TrkELSF-TrAX M '   1.1     45 -2152.75        21.5  3  1 2 6  414 416
  418
  449 'TrkERSF-LdAX M '   1.1 43  44 -2080.75  -39.5  21.5  3  1 2 6  415 417
  419
  450 'TrkERSF-TrAX M '   1.1 43  45 -2152.75  -39.5  21.5  3  1 2 6  415 417
  419
! Verical surface friction element for side frame to axle connection elements
! are placed +/- 3.0 inches apart to react roll, and pitch if the side frame
  451 'SdFm-Ax 7 L V L'       42  44 -2080.75   42.5  25.5  3 1 2  420
  452 'SdFm-Ax 7 L V R'   6.5  42     -2080.75   36.5  25.5  3 1 2  420
      'SdFm-Ax 7 R V R'   6.5         -2080.75  -42.5  25.5  3 1 2  420
  454 'SdFm-Ax 7 R V L'        43     -2080.75  -36.5  25.5  3 1 2  420
  455 'SdFm-Ax 8 L V L'   6.5  42  45 -2152.75   42.5  25.5  3 1 2  420
  456 'SdFm-Ax 8 L V R'   6.5  42     -2152.75   36.5  25.5  3 1 2  420
  457 'SdFm-Ax 8 R V R'   6.5  43     -2152.75  -42.5  25.5  3 1 2  420
  458 'SdFm-Ax 8 R V L'   6.5  43  45 -2152.75  -36.5  25.5  3 1 2  420
! Vertical side frame to axle connection damping
  459 'SdFm-Ax 7 L Vrt'    1  42  44 -2080.75   39.5  25.5  3  421
  460 'SdFm-Ax 7 R Vrt'    1  43     -2080.75  -39.5  25.5  3  421
  461 'SdFm-Ax 8 L Vrt'    1  42  45 -2152.75   39.5  25.5  3  421
  462 'SdFm-Ax 8 R Vrt'    1      45 -2152.75  -39.5  25.5  3  421
! Wheel/rail connections
  463 'Ax 7 Lt Wh/Rail'    4         -2080.75   29.75  0.0  7
      'Ax 7 Rt Wh/Rail'    4         -2080.75  -29.75  0.0  7
  465 'Ax 8 Lt Wh/Rail'    4         -2152.75   29.75  0.0  8
      'Ax 8 Rt Wh/Rail'    4   45    -2152.75  -29.75  0.0  8
! Truck Frame Bracing
! 463 'TrEFrame Brace1'    -1  42 43 -2238.75        6.50
!                                    -2277.25 -39.5  6.50  1  422
! 464 'TrEFrame Brace2'    -1  43 42 -2238.75 -39.5  6.50
!                                    -2277.25        6.50  1  422
! 66 + 191 =257 Connections
!
! Truck 5 or Truck F
! Truck Lateral and longitudinal connections for 16" center plate using
! 6.2 line friction element for rim friction at four corners
  501   'Ld CB-F  LgY LL'   6.2  51   5 -2810.75   8.0    23.0   2 1   500
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  502   'Ld CB-F  LgY LR'   6.2   5  51 -2810.75   -8.0    23.0   2 1   500
  503   'Ld CB-F  LtX Fr'   6.2  51   5 -2802.75    0.0    23.0   1 2   501
  504   'Ld CB-F  LtX Tr'   6.2   5  51 -2818.75    0.0    23.0   1 2   501
! Center Plate Rim Damping
  505   'Ld CB-F  LgY LL'   1.2  51   5 -2810.75    8.0    23.0   2    502
  506   'Ld CB-F  LgY LR'   1.2   5  51 -2810.75   -8.0    23.0   2    502
  507   'Ld CB-F  LtX Fr'   1.2  51   5 -2802.75    0.0    23.0   1    502
  508   'Ld CB-F  LtX Tr'   1.2   5  51 -2818.75    0.0    23.0   1    502
! Long./lat. car body center plate to bolster connections
! 509  'BolF-Plt4 L/L   '  1.1  4  51 -2810.75  0.0   23.0    2  1 2  5 6
! Vertical/Yaw for center plates line friction element
  509  'BolF Lft CP Con'  6.2  4  5  -2810.75   8.0  27.0  3  1  503
  510  'BolF Rgt CP Con'  6.2  4  5  -2810.75  -8.0  27.0  3  1  503
  511  'BolF Fr  CP Con'  6.2  4  5  -2802.75   0.0  27.0  3  2  503
  512  'BolF Tr  CP Con'  6.2  4  5  -2818.75   0.0  27.0  3  2  503
! Vertical centerplate connection damping
  513  'BolF Lf CP Damp'   1   4  5  -2810.75   8.0  27.0  3  504
  514  'BolF Rt CP Damp'   1   4  5  -2810.75  -8.0  27.0  3  504
  515  'BolF Fr CP Damp'   1   4  5  -2802.75   0.0  27.0  3  504
  516  'BolF Tr CP Damp'   1   4  5  -2818.75   0.0  27.0  3  504
! Vertical/Yaw for center plates line friction element
  517  'BolF Lft CP Con'  6.2  5  51 -2810.75   8.0  23.0  3  1  505
  518  'BolF Rgt CP Con'  6.2  5  51 -2810.75  -8.0  23.0  3  1  505
  519  'BolF Fr  CP Con'  6.2  5  51 -2802.75   0.0  23.0  3  2  505
  520  'BolF Tr  CP Con'  6.2  5  51 -2818.75   0.0  23.0  3  2  505
! Vertical centerplate connection damping
  521  'BolF Lf CP Damp'   1   5  51 -2810.75   8.0  23.0  3  504
  522  'BolF Rt CP Damp'   1   5  51 -2810.75  -8.0  23.0  3  504
  523  'BolF Fr CP Damp'   1   5  51 -2802.75   0.0  23.0  3  504
  524  'BolF Tr CP Damp'   1   5  51 -2818.75   0.0  23.0  3  504
! Constant Contact Side Bearings
  525  'BolF-CE Lft SB '  6.2  4  51 -2796.250   25.000  38.0  3  1  506
  526  'BolF-CE Rgt SB '  6.2  4  51 -2796.250  -25.000  38.0  3  1  506
  527  'BolF-CA Lft SB '  6.2  5  51 -2825.250   25.000  38.0  3  1  506
  528  'BolF-CA Rgt SB '  6.2  5  51 -2825.250  -25.000  38.0  3  1  506
! Constant Contact Side Bearings
  529  'BolF-CE Lft Gap'  1.2  4  51 -2796.250   25.000  38.0  3  507
  530  'BolF-CE Rgt Gap'  1.2  4  51 -2796.250  -25.000  38.0  3  507
  531  'BolF-CA Lft Gap'  1.2  5  51 -2825.250   25.000  38.0  3  507
  532  'BolF-CA Rgt Gap'  1.2  5  51 -2825.250  -25.000  38.0  3  507
! Bolster to side frame longitudinal,lateral and yaw connections
  533  '  BolF-SF M Lft'  1.1 51  52 -2810.75   39.5  14.5  4  1 2 5 6 508 509
  510 511
  534  '  BolF-SF M Rgt'  1.1 51  53 -2810.75  -39.5  14.5  4  1 2 5 6 508 509
  510 511
! 4-Vertical/Pitch bolster to side frame connections +/- 3.75
  535 'B5 Ld Bol-SF Lft'  1  51  52 -2807.00  35.75 14.5  3  512
  536 'B5 Ld Bol-SF Rgt'  1  51  53 -2807.00 -35.75 14.5  3  512
  537 'B5 Ld Bol-SF Lft'  1  51  52 -2807.00  43.25 14.5  3  512
  538 'B5 Ld Bol-SF Rgt'  1  51  53 -2807.00 -43.25 14.5  3  512
  539 'B5 Tr Bol-SF Lft'  1  51  52 -2814.50  35.75 14.5  3  512
  540 'B5 Tr Bol-SF Rgt'  1  51  53 -2814.50 -35.75 14.5  3  512
  541 'B5 Tr Bol-SF Lft'  1  51  52 -2814.50  43.25 14.5  3  512
  542 'B5 Tr Bol-SF Rgt'  1  51  53 -2814.50 -43.25 14.5  3  512
! 2D Friction wedge connection Between bolster and side frame
  543 '  BolF-SF TL Wg'  6.7 51  52 -2802.25  39.5  14.5  3  2  513
  544 '  BolF-SF TR Wg'  6.7 51  53 -2802.25 -39.5  14.5  3  2  513
  545 '  BolF-SF TL Wg'  6.7 51  52 -2819.25  39.5  14.5  3  2  513
  546 '  BolF-SF TR Wg'  6.7 51  53 -2819.25 -39.5  14.5  3  2  513
! Side frame to axle longitudinal, lateral, and yaw stops
  547 'TrkFLSF-LdAX M '  1.1 52  54 -2774.75   39.5  21.5  3  1 2 6  514 516
  518
  548 'TrkFLSF-TrAX M '  1.1 52  55 -2846.75   39.5  21.5  3  1 2 6  514 516
  518
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549 'TrkFRSF-LdAX M '   1.1 53      -2774.75  -39.5  21.5  3  1 2 6  5155

550 'TrkFRSF-TrAX M '   1.1         -2846.75  -39.5  21.5  3  1 2 6  515 517

! Verical surface friction element for side frame to axle connection elements
! are placed +/- 3.0 inches apart to react roll, and pitch if the side frame
  551 'SdFm-Ax 9 L V L'   6.5  52  54 -2774.75   42.5  25.5  3 1 2  520
  552 'SdFm-Ax 9 L V R'   6.5  52  54 -2774.75   36.5  25.5  3 1 2  520
  553 'SdFm-Ax 9 R V R'   6.5  53  54 -2774.75  -42.5  25.5  3 1 2  52055
  554 'SdFm-Ax 9 R V L'   6.5      54 -2774.75  -36.5  25.5  3 1 2  52055
  555 'SdFm-Ax10 L V L'   6.5  52  55 -2846.75   42.5  25.5  3 1 2  520
  556 'SdFm-Ax10 L V R'   6.5  52  55 -2846.75   36.5  25.5  3 1 2  520
      'SdFm-Ax10 R V R'   6.5      55 -2846.75  -42.5  25.5  3 1 2  52055
  558 'SdFm-Ax10 R V      6.5  53  55 -2846.75  -36.5  25.5  3 1 2  52055
! Vertical side frame to axle connection damping
      'SdFm-Ax 9 L Vrt'   1  52  54 -2774.75   39.5  25.5  3  521
  560 'SdFm-Ax 9 R Vrt'   1      54 -2774.75  -39.5  25.5  3  52155
  561 'SdFm-Ax10 L Vrt'   1  52  55 -2846.75   39.5  25.5  3  521
  562 'SdFm-Ax10 R Vrt'   1  53  55 -2846.75  -39.5  25.5  3  52155
! Wheel/rail connections
  563 'Ax 9 Lt Wh/Rail'   4   54    -2774.7555 29.75  0.0559
  564 'Ax 9 Rt Wh/Rail'   4         -2774.75  -29.75  0.0  955
  565 'Ax10 Lt Wh/Rail'5  4   55    -2846.7555 29.75  0.0 105
  566 'Ax10 Rt Wh/Rail'   4   55    -2846.75  -29.75550.0 105
! Truck Frame Bracing
! 567 'TrFFrame Brace1'   -1   52 53 -2988.75  39.5  6.5055
!                                  -3027.25 -39.5  6.50  1  52255
! 568 'TrFFrame Brace2'   -15     52 -2988.75 -39.5  6.5055
!                                  -3027.25  39.5  6.50  1  52255
! 66 + 257= 323 Connections
!
! Truck 6 or Truck A
! Truck Lateral and longitudinal connections for 16" center plate using
! 6.2 line friction element for rim friction at four corners
  601   'Ld CB-A  LgY LL'   6.2  61   5 -3505.5     7.0    23.0   2 1   600
  602   'Ld CB-A  LgY LR'   6.2   5  61 -3505.5    -7.055  23.0   2 1   600
  603   'Ld CB-A  LtX Fr'   6.2  61   5 -3498.5     0.055  23.0   1 2   601
  604   'Ld CB-A  LtX Tr'   6.2   5  61 -3512.5     0.055  23.0   1 2   601
! Center Plate Rim Damping
  605   'Ld CB-A  LgY LL'   1.2  61   5 -3505.5     7.0    23.0   2   602
  606   'Ld CB-A  LgY LR'   1.2   5  61 -3505.5    -7.055  23.0   2   602
  607   'Ld CB-A  LtX Fr'   1.2  61   5 -3498.5     0.0    23.0   1   602
  608   'Ld CB-A  LtX Tr'   1.2   5  61 -3512.5     0.0    23.0   1   602
! Long./lat. car body center plate to bolster connections
! 609  'BolA-Plt5 L/L  '  1.1  5  61 -3505.5  0.0    23.0    2  1 2  X Y
! Vertical/Yaw for center plates line friction element
  609  'BolA Lft CP Con'  6.2  5  61 -3505.5   7.0  23.0  3  1  603
  610  'BolA Rgt CP Con'  6.2  5  61 -3505.5  -7.0  23.0553  1  603
  611  'BolA Fr  CP Con'  6.2  5  61 -3498.5   0.0  23.0  3  2  603
  612  'BolA Tr  CP Con'  6.2  5  61 -3512.5   0.0  23.0  3  2  603
! Vertical centerplate connection damping
  613  'BolA Lf CP Damp'  1   5  61 -3505.5   8.0  23.0  3  604
  614  'BolA Rt CP Damp'  1   5  61 -3505.5  -8.05523.05 3  604
  615  'BolA Fr CP Damp'  1   5  61 -3498.5   0.05523.0  3  604
  616  'BolA Tr CP Damp'  1   5  61 -3512.5   0.05523.0  3  604
! Constant Contact Side Bearings
  617  'BolA-CA Lft SB5'  6.2  5  61 -3505.5   25.000  29.0  3  1  606
  618  'BolA-CA Rgt SB5'  6.2  5  61 -3505.5  -25.000  29.0  3  1  60655
! Constant Contact Side Bearings
  619  'BolA-CA Lft Gap'  1.2  5  61 -3505.5   25.000  29.0  3  607
  620  'BolA-CA Rgt Gap'  1.2  5  61 -3505.5  -25.000  29.0  3  60755
! Bolster to side frame longitudinal,lateral and yaw connections
  621  '  BolA-SF M Lft'  1.1 61  62 -3505.5   39.0  14.0  4 1 2 5 6 608 609
  610 611
```

```
  610 611
! 4-Vertical/Pitch bolster to side frame connections3+/- 3.75
  623 'B6 Ld Bol-SF Lft'   1  61  62 -3501.75  35.25 14.0  3  612
  624 'B6 Ld Bol-SF Rgt'   1  61  63 -3501.75 -35.25 14.0  3  61233
  625 'B6 Ld Bol-SF Lft'   1  61  62 -3501.75  42.75 14.0  3  612
  626 'B6 Ld Bol-SF Rgt'   1  61  63 -3501.75 -42.75 14.0  3  61233
  627 'B6 Tr Bol-SF Lft'   1  61  62 -3509.25  35.25 14.0  3  612
  628 'B6 Tr Bol-SF Rgt'   1  61  63 -3509.25 -35.25 14.0  3  612
  629 'B6 Tr Bol-SF Lft'   1  61  62 -3509.25  42.75 14.0  3  612
  630 'B6 Tr Bol-SF Rgt'   1  61  63 -3509.25 -42.75 14.0  3  612
! 2D Friction wedge connection Between bolster and side frame
  631 '  BolA-SF LL Wg'   6.7 61  62 -3497.0  39.0  14.5  3  2  613
  632 '  BolA-SF LR Wg'   6.7 61  63 -3497.0 -39.0  14.5  3  2  61333
  633 '  BolA-SF LL Wg'   6.7 61  62 -3514.0  39.0  14.5  3  2  613
  634 '  BolA-SF LR Wg'   6.7 61  63 -3514.0 -39.0  14.5  3  2  61333
! Side frame to axle longitudinal, lateral, and yaw stops
  635 'TrkALSF-LdAX M ' 3 3.1 62  64 -3471.5   39.0  20.0  3  1 2 6  614 616
  618
  636 'TrkALSF-TrAX M ' 3 1.1 62  65 -3539.5   39.0  20.0  3  1 2 6  614 616
  618
  637 'TrkARSF-LdAX M ' 3 1.1 63  64 -3471.5  -39.0  20.0  3  1 2 6  615 61733
  619
  638 'TrkARSF-TrAX M ' 3 1.1 63  65 -3539.5  -39.0  20.0  3  1 2 6  615 61733
  619
! Verical surface friction element for side frame to axle connection elements
! are placed +/- 3.0 inches apart to react roll, and pitch if the side frame
! Truck A
  639 'SdFm-Ax11 L V L'   6.5  62  64 -3471.5   42.0  24.0  3 1 2  620
  640 'SdFm-Ax11 L V R'   6.5  62  64 -3471.5   36.0  24.0  3 1 2  620
  641 'SdFm-Ax11 R V R'   6.5  63  64 -3471.5  -42.0  24.0  3 1 2  6203
  642 'SdFm-Ax11 R V L'   6.5  63  64 -3471.5  -36.03324.0  3 1 2  6203
  643 'SdFm-Ax12 L V L'   6.5  62  65 -3539.5   42.0  24.0  3 1 2  620
  644 'SdFm-Ax12 L V R'   6.5  62  65 -3539.5   36.0  24.0  3 1 2  620
  645 'SdFm-Ax12 R V R'   6.5  63  65 -3539.5  -42.03324.0  3 1 2  6203
  646 'SdFm-Ax12 R V L'   6.5  63  65 -3539.5  -36.03324.0  3 1 2  6203
! Vertical side frame to axle connection damping
  647 'SdFm-Ax11 L Vrt'    1  62  64 -3471.5   39.0  21.5  3  621
  648 'SdFm-Ax11 R Vrt'    1  63  64 -3471.5  -39.03321.5  3  62133
  649 'SdFm-Ax12 L Vrt'    1  62  65 -3539.5   39.0  21.5  3  62133
  650 'SdFm-Ax12 R Vrt'    1  63  65 -3539.5  -39.03321.5  3  62133
! Wheel/rail connections
  651 'Ax11 Lt Wh/Rail'    4   64     -3471.533 29.75  0.0 113
  652 'Ax11 Rt Wh/Rail'    4   64     -3471.533-29.75330.0 11
  653 'Ax12 Lt Wh/Rail'    4   65     -3539.533 29.75330.0 123
  654 'Ax12 Rt Wh/Rail'    4   65     -3539.533-29.75330.0 123
! Truck Frame Bracing
! 655 'TrAFrame Brace1'    -13362 63 -3712.753339.0  6.503
!                                    -3751.253-39.0336.50  1  6223
! 656 'TrAFrame Brace2'    -1   63 62 -3712.753-39.0336.50
!                                    -3751.253339.0336.50  1  6223
! 54 + 323 =377 Connections
!
! Dummy Connections
  901 'Dummy BolB CB  '   1.1    1  11    -34.00  0.033 25.0  3 4 5 6 700 7003
  700
  902 'Dummy BolC CB  '   1.1    1  21   -728.75  0.0   25.0  3 4 5 6 700 700
  700
  903 'Dummy BolC CC  '   1.1    2  21   -728.75  0.0   25.0  3 4 5 6 700 700
  700
  904 'Dummy BolD CC  '   1.1    2  31 -1422.75  0.0   25.0  3 4 5 6 700 700
  700
  905 'Dummy BolD CD  '   1.1    3  31 -1422.75  0.0   25.0  3 4 5 6 700 700
  700
```

```
  906 'Dummy BolE CD  '   1.1   3  41 -2116.75  0.0   25.0  3 4 5 6 700 700
  700
  907 'Dummy BolE CE  '   1.1   4  41 -2116.75  0.0   25.0  3 4 5 6 700 700
  700
  908 'Dummy BolF CE  '   1.1   4  51 -2810.75  0.0   25.0  3 4 5 6 700 700
  700
  909 'Dummy BolF CA  '   1.1   5  51 -2810.75  0.0   25.0  3 4 5 6 700 700
  700
  910 'Dummy BolA CA  '   1.1   5  61 -3505.50  0.0   25.0  3 4 5 6 700 700
  700
!
! 10 +      =387 connections

 Pair #  Stiffness & Damping  F/S-extn.  F/S-comp.    K/D-parameters
-----------------------------------------------------------------------
\CHARACTERISTIC DATA
!
! Articulations
!
! Tow spring
   1    1    2          1.0E09     -1.0E09
! Longitudinal articulated connector connection
   2    3    4          1.0E09     -1.0E09
! Lateral articulated connector connection
   3    3    4          1.0E09     -1.0E09
! Vertical articulated connector connection
!  4    3    4          1.0E09     -1.0E09
! Characteristic data for vertical articulated connectors with preloads
! Vertical articulated connector connection
!
! Truck C
!  5    5    6          1.0E09     -1.0E0900
! Truck D
!  6    7    6          1.0E0900   -1.0E0900
! Truck E
!  7    8    6          1.0E09     -1.0E0900
! Truck F
!  8    9    6          1.0E09     -1.0E0900
!
! Dummy data for 1.3 articulated connection
   9    0    0          1.0E9      -1.0E90
!
! ***************************** Truck B
*******************************************
!
! Center plate longitudinal and lateral rim friction
  100  110    0     1.0         -1.000   0.0     1.0E06001.0E03  0.50
  101  110    0     1.0         -1.000   0.0     1.0E06001.0E03000.50
! New Damping for Friction Elements, 6.2 6.5
! Center Plate Rim
  102    0  111          1000.0    -0.12500
! 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 at0the 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
! to0each other produces the effective Mu, R relationship.  Therefore,Mu1*2/3
! = Mu2.  For this simulation Mu1 was assumed to be 0.3 producing
! an effective Mu2 for the 6.2 connection of 0.2
! Truck B
! Verticals
  103  112    0         1.0E0900   -1.0E09  0.0E08001.0E06  1.0E03 0.33300
! Centerbowl damping with liftoff
  104    0  111         0.0E900    -1.0E900
! 105 Left Blank for consistancy uses PWL113
```

```
!
!
!
!
! 107    3    4          1000.0    -0.25e
! Longitudinal bolster to side frame
  108    3    4         1.0E09     -1.0E09e
! Lateral bolster to side frame
  109  116    0         1.0E09     -1.0E09ee
! Pitch bolster to side frame
  110  117    0         1.0E09ee   -1.0E09ee
! Truck bolster to side frame torsion spring, warp
  111  118    0         1.0E09     -1.0E09ee
! Truck vertical and pitch bolster to side frame connections
  112  119    0         1.0E09     -1.0E09e
! Constant force wedge with wedge angle
  113    0    0       37.5   3100.0   1.0E04  0.40  0.40 .T.e
! Variable force wedge with wedge angle
! 113  120    0       32.9      0.0   1.0E04  0.32  0.32 .T.ee
! Axle to side frame longitudinal (Left)
  114  121    0         1.0E09ee   -1.0E09ee
! Axle to side frame longitudinal (Right)
  115  122    0         1.0E09     -1.0E09ee
! Axle to side frame lateral (Left)
  116  123    0         1.0E09ee   -1.0E09ee
! Axle to side frame lateral (Right)
  117  124    0         1.0E09     -1.0E09ee
! Axle to side frame yaw (Left)
  118  125    0         1.0E09ee   -1.0E09ee
! Axle to side frame yaw (Right)
  119  126    0         1.0E09     -1.0E09ee
! Axle to side frame vertical/yaw friction elements, R=2.0, Mu*R, Mu=.5\ee
! Vertical side frame to axle connections with friction, type 6.5
  120  127    0       1.0E6ee     1.0E3    0.5
! Damping axle to side frame
  121    0  128       0.0E8ee     -1.0E8ee
! Frame Brace
! 122  129  130       1.0E9ee     -1.0E9
! **************************** Truck C *****************************ee
!
! Center plate longitudinal and lateral rim friction
  200  210    0    1.0        -1.0ee   0.0     1.0E06  1.0E03  0.5ee
  201  210    0    1.0        -1.0ee   0.0     1.0E06  1.0E03  0.5ee
! New Damping for Friction Elements, 6.2 6.5
! Center Plate Rim
  202    0  211       1000.0    -0.125
! The normal formula for calculating the center plate breakout
! torque for one bowl is (Cw*Mu1*R)/3.  This model assumes all loads areee
! 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.  For this simulation Mu1 was assumed to be 0.3 producing
! an effective Mu2 for the 6.2 connection of 0.2
! Verticals Top
  203  212    0       1.0E09ee    -1.0E09  0.0E08  1.0E06  1.0E03 0.333ee
! Centerbowl damping with liftoff
  204    0  211       0.0E9ee     -1.0E9ee
! Verticals Bottom
  205  213    0       1.0E09      -1.0E09  0.0E08  1.0E06  1.0E03 0.333ee
! Constant contact side bearings
  206  214  215      1.0E09      -1.0E09  0.0E0ee 1.0E6ee 1.0E3ee 0.4e
! <<<<<<<<<<<<<<< Set for Specific Side Bearing >>>>>>>>>>>>>>>>>>>>>>>>>>
```

```
!
  207    3    4         1000.0    -1000
! Roller side bearings for roller assit CCSB's
! 207    3    4         1000.0    -0.25
! Longitudinal bolster to side frame
  208    3    4        1.0E09     -1.0E09
! Lateral bolster to side frame
  209  216    0        1.0E09ee   -1.0E09ee
! Pitch bolster to side frame
  210  217    0        1.0E09ee   -1.0E09ee
! Truck bolster to side frame torsion spring, warp
  211  218    0        1.0E09ee   -1.0E09ee
! Truck vertical and pitch bolster to side frame connections
  212  219    0        1.0E09     -1.0E09ee
! Constant force wedge with wedge angle
! 213    0    0       37.5   3100.0   1.0E04  0.40  0.40 .T.
! Variable force wedge with wedge angle
  213  220    0       32.0      0.0   1.0E04  0.32  0.32 .T.
! Axle to side frame longitudinal (Left)
  214  221    0        1.0E09ee   -1.0E09ee
! Axle to side frame longitudinal (Right)
  215  222    0        1.0E09ee   -1.0E09ee
! Axle to side frame lateral (Left)
  216  223    0        1.0E09     -1.0E09ee
! Axle to side frame lateral (Right)
  217  224    0        1.0E09     -1.0E09ee
! Axle to side frame yaw (Left)
  218  225    0        1.0E09ee   -1.0E09ee
! Axle to side frame yaw (Right)
  219  226    0        1.0E09     -1.0E09ee
! Axle to side frame vertical/yaw friction elements, R=2.0, Mu*R, Mu=.5\ee
! Vertical side frame to axle connections with friction, type 6.5
  220  227    0        1.0E6ee     1.0E3    0.5
! Damping axle to side frame
  221    0  228       0.0E8ee    -1.0E8ee
! Frame Brace
! 222  229  230        1.0E9      -1.0E9
! *************************** Truck D ***************************ee
!
! Center plate longitudinal and lateral rim friction
  300  310    0     1.0        -1.0ee   0.0     1.0E06ee1.0E03ee0.5e
  301  310    0     1.0        -1.0ee   0.0     1.0E06ee1.0E03ee0.5e
! New Damping for Friction Elements, 6.2 6.5
! Center Plate Rim
  302    0  311       1000.0    -0.125
! The normal formula for calculating the center plate breakout
! torque for one bowl is (Cw*Mu1*R)/3.  This model assumes all loads areee
! 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.  For this simulation Mu1 was assumed to be 0.3 producing
! an effective Mu2 for the 6.2 connection of 0.2
! Verticals Top
  303  312    0       1.0E09     -1.0E09  0.0E08  1.0E06  1.0E03 0.333ee
! Centerbowl damping with liftoff
  304    0  311       0.0E9ee    -1.0E9ee
! Verticals Bottom
  305  313    0       1.0E09     -1.0E09  0.0E08  1.0E06  1.0E03 0.333ee
! Constant contact side bearings
  306  314  315       1.0E09     -1.0E09  0.0E0ee 1.0E6e  1.0E3ee 0.4e
! <<<<<<<<<<<<<< Set for Specific Side Bearing >>>>>>>>>>>>>>>>>>>>>>>>>
! Roller side bearings for roller assit CCSB's
  307    3    4       1000.0    -1000
! Roller side bearings for roller assit CCSB's
```

```
!        3    4         1000.0    -0.25
! Longitudinal bolster to side frame
  308    3    4        1.0E09     -1.0E09
! Lateral bolster to side frame
  309  316    0        1.0E09     -1.0E09
! Pitch bolster to side frame
  310  317    0        1.0E09     -1.0E09
! Truck bolster to side frame torsion spring, warp
  311  318    0        1.0E09     -1.0E09
! Truck vertical and pitch bolster to side frame connections
  312  319    0        1.0E09     -1.0E09
! Constant force wedge with wedge angle
! 313    0    0       37.5   3100.0   1.0E04  0.40  0.40 .T.
! Variable force wedge with wedge angle
  313  320    0       32.0      0.0   1.0E04  0.32  0.32 .T.
! Axle to side frame longitudinal (Left)
       321    0        1.0E09     -1.0E09
! Axle to side frame longitudinal (Right)
  315  322    0        1.0E09     -1.0E09
! Axle to side frame lateral (Left)
  316  323    0        1.0E09     -1.0E09
! Axle to side frame lateral (Right)
  317  324    0        1.0E09     -1.0E09
! Axle to side frame yaw (Left)
  318  325    0        1.0E09     -1.0E09
! Axle to side frame yaw (Right)
  319  326    0        1.0E09     -1.0E09
! Axle to side frame vertical/yaw friction elements, R=2.0, Mu*R, Mu=.5\
! Vertical side frame to axle connections with friction, type 6.5
  320  327    0        1.0E6       1.0E3    0.5
! Damping axle to side frame
  321    0  328        0.0E8      -1.0E8
! Frame Brace
! 322  329  330        1.0E9      -1.0E9
! *************************** Truck E ***************************
!
! Center plate longitudinal and lateral rim friction
  400  410    0     1.0        -1.0     0.0     1.0E06  1.0E03  0.5
  401  410    0     1.0        -1.0     0.0     1.0E06  1.0E03  0.5
! New Damping for Friction Elements, 6.2 6.5
! Center Plate Rim
  402    0  411        1000.0    -0.125
! 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.  For this simulation Mu1 was assumed to be 0.3 producing
! an effective Mu2 for the 6.2 connection of 0.2
! Verticals Top
  403  412    0        1.0E09     -1.0E09  0.0E08  1.0E06  1.0E03 0.333
! Centerbowl damping with liftoff
  404    0  411        0.0E9      -1.0E9
! Verticals Bottom
  405  413    0        1.0E09     -1.0E09  0.0E08  1.0E06  1.0E03 0.333
! Constant contact side bearings
  406  414  415        1.0E09     -1.0E09  0.0E0   1.0E6   1.0E3   0.4
! <<<<<<<<<<<<<< Set for Specific Side Bearing >>>>>>>>>>>>>>>>>>>>>>>>>
! Roller side bearings for roller assit CCSB's
  407    3    4         1000.0    -1000
! Roller side bearings for roller assit CCSB's
! 407    3    4         1000.0    -0.25
! Longitudinal bolster to side frame
  408    3    4        1.0E09     -1.0E09
```

```
!
  409  416    0         1.0E09     -1.0E09
! Pitch bolster to side frame
  410  417    0         1.0E09     -1.0E09
! Truck bolster to side frame torsion spring, warp
  411  418    0         1.0E09     -1.0E09
! Truck vertical and pitch bolster to side frame connections
  412  419    0         1.0E09     -1.0E09
! Constant force wedge with wedge angle
! 413    0    0       37.5   3100.0   1.0E04  0.40  0.40 .T.
! Variable force wedge with wedge angle
  413  420    0       32.0      0.0   1.0E04  0.32  0.32 .T.
! Axle to side frame longitudinal (Left)
  414  421    0         1.0E09     -1.0E09
! Axle to side frame longitudinal (Right)
  415  422    0         1.0E09     -1.0E09
! Axle to side frame lateral (Left)
  416  423    0         1.0E09     -1.0E09
! Axle to side frame lateral (Right)
  417  424    0         1.0E09     -1.0E09
! Axle to side frame yaw (Left)
  418  425    0         1.0E09     -1.0E09
! Axle to side frame yaw (Right)
  419  426    0         1.0E09     -1.0E09
! Axle to side frame vertical/yaw friction elements, R=2.0, Mu*R, Mu=.5\
! Vertical side frame to axle connections with friction, type 6.5
  420  427    0         1.0E6       1.0E3    0.5
! Damping axle to side frame
  421    0  428         0.0E8      -1.0E8
! Frame Brace
! 422  429  430         1.0E9      -1.0E9
! **************************** Truck F ****************************
!
! Center plate longitudinal and lateral rim friction
  500  510    0     1.0        -1.0     0.0     1.0E06  1.0E03  0.5
  501  510    0     1.0        -1.0     0.0     1.0E06  1.0E03  0.5
! New Damping for Friction Elements, 6.2 6.5
! Center Plate Rim
  502    0  511         1000.0    -0.125
! 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.  For this simulation Mu1 was assumed to be 0.3 producing
! an effective Mu2 for the 6.2 connection of 0.2
! Verticals Top
  503  512    0         1.0E09     -1.0E09  0.0E08  1.0E06  1.0E03 0.333
! Centerbowl damping with liftoff
  504    0  511         0.0E9      -1.0E9
! Verticals Bottom
  505  513    0         1.0E09     -1.0E09  0.0E08  1.0E06  1.0E03 0.333
! Constant contact side bearings
  506  514  515         1.0E09     -1.0E09  0.0E0   1.0E6   1.0E3   0.4
! <<<<<<<<<<<<<< Set for Specific Side Bearing >>>>>>>>>>>>>>>>>>>>>>>>>
! Roller side bearings for roller assit CCSB's
  507    3    4          1000.0    -1000
! Roller side bearings for roller assit CCSB's
! 507    3    4          1000.0    -0.25
! Longitudinal bolster to side frame
  508    3    4         1.0E09     -1.0E09
! Lateral bolster to side frame
  509  516    0         1.0E09     -1.0E09
! Pitch bolster to side frame
```

```
!
! Truck vertical and pitch bolster to side frame connections
  512  519    0         1.0E09ee   -1.0E09ee
! Constant force wedge with wedge angle
! 513    0    0       37.5    3100.0    1.0E04  0.40   0.40 .T.
! Variable force wedge with wedge angle
  513  520    0       32.0       0.0    1.0E04  0.32   0.32 .T.ee
! Axle to side frame longitudinal (Left)
  514  521    0         1.0E09      -1.0E09ee
! Axle to side frame longitudinal (Right)
  515  522    0         1.0E09e     -1.0E09ee
! Axle to side frame lateral (Left)
  516  523    0         1.0E09ee    -1.0E09ee
! Axle to side frame lateral (Right)
  517  524    0         1.0E09      -1.0E09ee
! Axle to side frame yaw (Left)
  518  525    0         1.0E09      -1.0E09ee
! Axle to side frame yaw (Right)
  519  526    0         1.0E09ee    -1.0E09ee
! Axle to side frame vertical/yaw friction elements, R=2.0, Mu*R, Mu=.5\ee
! Vertical side frame to axle connections with friction, type 6.5
  520  527    0         1.0E6        1.0E3    0.5
! Damping axle to side frame
  521    0  528         0.0E8ee     -1.0E8ee
! Frame Brace
! 522  529  530         1.0E9ee     -1.0E9
! ****************************** Truck A
*******************************************
!
! Center plate longitudinal and lateral rim friction
  600  610    0     1.0         -1.0ee    0.0     1.0E06  1.0E03  0.5
  601  610    0     1.0         -1.0ee    0.0     1.0E06ee1.0E03ee0.5e
! New Damping for Friction Elements,e 6.2 6.5
! Center Plate Rim
  602    0  611         1000.0    -0.125e
! The normal formula for calculating the center plate breakout
! torque for one bowl is (Cw*Mu1*R)/3.  This model assumes all loads areee
! 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.eeFor this simulation Mu1 was assumed to be 0.3 producinge
! an effective Mu2 for the 6.2 connection of 0.2
! Truck B
! Verticals
  603  612    0         1.0E09ee    -1.0E09  0.0E08ee1.0E06ee1.0E03 0.333ee
! Centerbowl damping with liftoff
  604    0  611         0.0E9ee     -1.0E9ee
! 105 Left Blank for consistancy uses PWL113
! Constant contact side bearings
  606  614  615         1.0E09ee    -1.0E09  0.0E0ee 1.0E6ee 1.0E3ee 0.4e
! <<<<<<<<<<<<<< Set for Specific Side Bearing >>>>>>>>>>>>>>>>>>>>>>>>>
! Roller side bearings for roller assit CCSB's
  607    3    4          1000.0    -1000
! Roller side bearings for roller assit CCSB's
! 607    3    4          1000.0    -0.25
! Longitudinal bolster to side frame
  608    3    4         1.0E09      -1.0E09
! Lateral bolster to side frame
  609  616    0         1.0E09      -1.0E09ee
! Pitch bolster to side frame
  610  617    0         1.0E09      -1.0E09ee
! Truck bolster to side frame torsion spring, warp
```

```
!
  612  619    0         1.0E09     -1.0E09
! Constant force wedge with wedge angle
  613    0    0        37.5   3100.0   1.0E04  0.40  0.40 .T.
! Variable force wedge with wedge angle
! 613  620    0        32.0      0.0   1.0E04  0.32  0.32 .T.
! Axle to side frame longitudinal (Left)
  614  621    0         1.0E09     -1.0E09
! Axle to side frame longitudinal (Right)
  615  622    0         1.0E09     -1.0E09
! Axle to side frame lateral (Left)
  616  623    0         1.0E09     -1.0E09
! Axle to side frame lateral (Right)
  617  624    0         1.0E09     -1.0E09
! Axle to side frame yaw (Left)
  618  625    0         1.0E09     -1.0E09
! Axle to side frame yaw (Right)
  619  626    0         1.0E09     -1.0E09
! Axle to side frame vertical/yaw friction elements, R=2.0, Mu*R, Mu=.5\
! Vertical side frame to axle connections with friction, type 6.5
  620  627    0        1.0E6      1.0E3    0.5
! Damping axle to side frame
  621    0  628        0.0E8      -1.0E8
! Frame Brace
! 622  629  630        1.0E9      -1.0E9
! Dummy data for Center Bowl Yaw connection
  700    0    0        1.0E9      -1.0E9

   Axle #     WRAD     INDWH     ITRQ-L   ITRQ-R     KWHL     DWHL
------------------------------------------------------------------------
\WHEEL/RAIL ELEMENT
    1.E5     1.E3   2.50E5   2.50E3
     1        16.5       .F.        0        0
     2        16.5       .F.        0        0
     3        19.0       .F.        0        0
     4        19.0       .F.        0        0
     5        19.0       .F.        0        0
     6        19.0       .F.        0        0
     7        19.0       .F.        0        0
     8        19.0       .F.        0        0
     9        19.0       .F.        0        0
    10        19.0       .F.        0        0
    11        16.5       .F.        0        0
    12        16.5       .F.        0        0

    PWL    IBP    Ordinates over Abscissae
------------------------------------------------------------------------
\PWL DATA
! Tow spring
    1      2      0.0      5.0E3
                  0.0      1.0
    2      2      0.0      1.0E2
                  0.0      1.0
! Steel-on-steel connections
    3      2      0.0      1.0E7
                  0.0      1.0
    4      2      0.0      1.0E3
                  0.0      1.0
! Center plate lift-off spring
! Truck C
!   5      3     -1.0E7    0.0      0.0
!                -1.0      0.0      1.0
!
```

```
!   6       2       0.0       1.0E300
!                   0.0       1.000
! Truck D
!   7       3     -1.0E700  0.0       0.0
!                 -1.000    0.0       1.0
! Truck E
!   8       3     -1.0E700  0.0       0.0
!                 -1.000    0.0       1.0
! Truck F
!   9       3     -1.0E700  0.0       0.0
!                 -1.000    0.0       1.0
!
! <<<<<<<<<<<<<<<<<<<<<<<<<< Truck B >>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>
!
! ********************** Center plate Connections00***************************
! Longitudinal and lateral rim normal stiffness and damping,
! Steel on steel, with 80 lb/in  +/-0.125 inch gap
  110       4    -1.101E3   -10.0   0.0  0.0
                   -0.12600 -0.125  0.0  1.000
  111       2       0.000    1.E300
                    0.000    1.000
! Verticals
! Empty 2000 using 9000 at CCSB's
! Loaded 17038 using 9000 at CCSB's
!Empty
!0011200    3      -153500   0.0          0.0
!                   0.000    0.0001535   1.0
!Loaded00
  11200    3      -1666500  0.0       0.0
                   0.0      0.00166  1.0
! 113 not used
! Side Bearings
! ********************** Constant Contact Side Bearings0**********************00
! ****************************0Miner's0*****************************00
! TCC-III-LT Sidebearing. Works for the RA if the gap is Roller SB is set to
go solid at -0.3125.
!   114      6       -10500    -9500     -7000   -540000  0.0        0.0
!                  -0.62600  -0.62500  -0.312500 0.00   1.1625     1.2625
! MINER TCC-III-45 ST
!   114      6       -680000      -580000      -430000  -1800   0.0   0.0
!                   -0.313500    -0.31250       0.0             0.8   0.9
! MINER TCC-III-45 RA  (Must turn on Roller SB when using this PWL)
!   114      5     -580000      -4300    -1800   0.0    0.00
!                  -0.312500      0.0      0.5   0.8    0.9
! TCC-III-45 Long Travels
    114      7    -8800  -780000-5800  -4300  -180000 0.0  0.00
                  -0.626 -0.625 -0.3125  0.000 0.500  1.0  2.0
! MINER TCC-III-45 LT
!   114      7    -880000  -780000      -580000      -430000   -180000 0.00  0.0
!                 -0.62600  -0.62500    -0.312500      0.0       0.5   0.8   0.900
! TCC-III-45-RA Roller assist CCSB
!
! TCC-II-60 Miner 6000 lb pre-load
! Re-calculated
!   114      8      -22.0E3   -12.0E3  -9.0E3  -6.0E3  -3.5E3  -2.0E3  0.000
0.0
!                   -0.6100   -0.600   -0.400  0.0      0.4     0.70   0.8  1.0
!
! ********************** Constant Contact Side Bearings0**********************00
! **************************** Stucki's ****************************
!
!  ISB 9-DR ISB-9DR-B Roller assist CCSB
!   114      9     -13500  -13500 -11500  -550000 -4000 -250000 -1000    0.0
```

```
!
!
!
-100000  0.0
!                 -0.2600  -0.25  -0.1875 -0.031300 0.00  0.0313  0.1094
0.1875  0.2813  0.4375
!
!  ISB12 6000 lb pre-load (Roller Assist)
!   114      7    -1.68E4   -1.1E400  -6.0E300  -3.0E300  -8.0E200 0.00   0.0
!                 -0.2500   -0.12500   0.000     0.12500   0.2500  0.375
0.385
!
!  ****************************0Miner's0****************************0
!
! Constant contact side bearings:  Preliminary TCC3-60 Characteristic
!   114      5     -1.0E7   -1.35E400  -6.0E300 0.00    0.0
!                  -1.62500 -0.6200     0.000   1.09    2.0
! Constant contact side bearings MINER TCC-III-45 Long-travel w/ 4800lb
pre-load
!00 11400   10    -1.0E7  -1.0E4  -8.0E3  -6.0E3  -4.8E300
!                 -4.0E3  -3.0E3  -2.0E3   0.0     0.0
!                 -1.62   -0.62   -0.42   -0.17    0.0
!                  0.13    0.28    0.46    0.93    1.83
! Constant contact side bearings Stucki 656-CRH w/ 6000lb pre-load
!   114     11    -1.0E7   -16600   -10900   -6300   -435000
!                 -280000   -170000   -80000  -30000   0.0   0.0
!                 -1.2500  -0.2500  -0.12500  0.000 0.0625
!                  0.125    0.187500 0.2500   0.312500 0.375 1.375
! Constant contact side bearings (hypothetical) 3000lb pre-load
!   114     10    -1.0E7  -1.0E4  -8.0E3  -6.0E3  -4.8E3
!                 -4.0E3  -3.0E3  -2.0E300 0.00    0.0
!                 -1.9000 -0.9000 -0.7000 -0.4500 -0.2800
!                 -0.1500  0.000   0.1800  0.6500  1.55
!******************************** Damping
****************************************
! Low damping to ensure proper roll
!  115       3     0.0       1.0E200 1.0E200
!                  0.0       0.02500 1.000
   115       3     0.0       5.0E200 5.0E200
                   0.0       0.02500 1.000
!
! Truck B **************************************************00
!
! VERTICAL SUSPENSION WITH STATIC DEFLECTIONS FOR  4 EQUIVALENT SPRINGS
!  7-D5 OUTER00 3-D6 INNER SPRINGS00
! FRICTION WEDGE CONTROL SPRING STIFFNESS FOR 2 EQUIVALENT SPRINGS
! ** NOTE: CALCULATIONS OF EQUIVALENT SPRINGS DO NOT ACCOUNT00
!          FOR THE PITCH MOMENT OF THE BOLSTER0**00
!
! Empty Lateral
! Lateral bolster to side frame
! 116   3    0.000E+0  4.868E+3  1.049E+500
!            0.0000    0.5000    0.6000
! Loaded Lateral
! Lateral bolster to side frame)
  116   3    0.000E+0  6.297E+3  1.063E+500
             0.0000    0.5000    0.6000
! Pitch Stiffness and Stops Mid Tolerance is Approx0+/- 2.4 Degrees=0.042mRad
  117   3    0.0       0.0    6.40E7
             0.0       0.042  1.042
! Empty Warp
! Empty
! Truck bolster to side frame torsion spring
```

```
!
!             0.0000    0.0300    0.0400
! Loaded Warp
! Truck bolster to side frame torsion spring
  118   3    0.000E+0  1.345E+4  6.535E+5
             0.0000    0.0300    0.0400
! Empty Vertical
! 119   6   -4.300E+4 -1.800E+4 -2.298E+3 -1.226E+3  0.000E+0  0.000E+0
!           -3.2592   -3.1592    0.0000    0.2158    0.5283    1.5283
! Loaded Vertical
! Truck Bolster to Side Frame Vertical Spring: 1/4 spring group
  119   6   -4.300E+4 -1.800E+4 -9.814E+3 -1.226E+3  0.000E+0  0.000E+0
            -1.7466   -1.6466    0.0000    1.7284    2.0409    3.0409
!
! Empty Wedges
! NA
! Friction Wedge Control Spring Stiffness:
! 120   6    -2.00E6   -6.53E3  -1.44E3   -6.44E1   0.0   0.0
!            -4.413    -3.413    0.0       0.925    0.987 1.0
! Loaded Wedges
! Friction Wedge Control Spring Stiffness:
! 120   6    -2.00E6   -6.53E3  -1.44E3   -6.44E1   0.0   0.0
!           -4.413    -3.413    0.0       0.925    0.987 1.0
!********************** Bearing Adapter Side Frame to Axle
*********************
!
! Bearing adapter stops
! 70 Ton 39 * 2= 78 inches
! 2mRad = 0.078
! 4mRad = 0.156
! 6mRad = 0.234
!
! Left Longitudinal Stiffness with Stops
  121      3      0.0    1.0     1.E3
                  0.0    0.0468  0.0478
! Right Longitudinal Stiffness with Stops
  122      3      0.0    1.0     1.E3
                  0.0    0.0468  0.0478
! Left Lateral Stiffness with Stops
  123      3      0.0    1.0     1.E3
                  0.0    0.250   0.251
! Right Lateral Stiffness with Stops
  124      3      0.0    1.0     1.E3
                  0.0    0.250   0.251
! Left Yaw Stiffness with Stops
  125      3      0.0    0.0     6.4E5
                  0.0    0.030   0.040
! Right Yaw Stiffness with Stops
  126      3      0.0    0.0     6.4E5
                  0.0    0.030   0.040
! Verticals
! Empty 2553
! Loaded 10072
! Vertical Bearing Adapter connection with offsets
!Empty
! 127      3     -2775       0.0       0.0
!                 0.0        0.002775  1.0
!Loaded
  127      3     -9840       0.0       0.0
                  0.0        0.009840  1.0
  128      2      0.0        1.0E3
                  0.0        1.0
! Frame brace characteristic(from Std Car: 140,000lb/in per pad set)
! 129      2      0.0    7.0E4
```

```
!                  0.0     1.0
!           2      0.0     1.0E2
!                  0.0     1.0
!
! <<<<<<<<<<<<<<<<<<<<<<<<<< Truck C >>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>
!
! ********************** Center plate Connections ****************************
! Longitudinal and lateral rim normal stiffness and damping,
! Steel on steel, with 80 lb/in  +/-0.125 inch gap
  210      4    -1.101E3   -10.0   0.0  0.0
                  -0.126   -0.125  0.0  1.0
  211      2       0.0      1.E3
                   0.0      1.0
! Verticals Top
! Empty
! Top 1734
! Bottom 4908
! Loaded
! Top 16772
! Bottom 34983
!
! Empty Top
! 212      3      -1606     0.0         0.0
!                  0.0      0.0001606   1.0
! Empty Bottom
! Verticals Bottom
! 213      3      -2595     0.0         0.0
!                  0.0      0.0002595   1.0
! Loaded Top - Curt's original
! 212      3      -11740    0.0         0.0
!                  0.0      0.0011740   1.0
! Loaded Top - Adjusted STG
  212      4      -23480        -11740    0.0        0.0
                  -0.011174     -0.01     0.11740    1.0
! Loaded Bottom
! Verticals Bottom
  213      3      -32460    0.0         0.0
                   0.0      0.0032460   1.0
!
! Side Bearings
! ********************** Constant Contact Side Bearings **********************
! **************************** Miner's ****************************
! TCC-III-LT Sidebearing. Works for the RA if the gap is Roller SB is set to
go solid at -0.3125.
!   214      6       -10500     -9500     -7000    -5400     0.0        0.0
!                   -0.626    -0.625    -0.3125   0.0     1.1625     1.2625
! MINER TCC-III-45 ST
!   214      6      -6800        -5800        -4300     -1800    0.0    0.0
!                   -0.3135      -0.3125          0.0       0.5    0.8    0.9
! MINER TCC-III-45 RA  (Must turn on Roller SB when using this PWL)
!   214      5     -5800        -4300     -1800    0.0    0.0
!                  -0.3125         0.0       0.5    0.8    0.9
! TCC-III-45 Long Travels
    214      7     -8800  -7800  -5800  -4300  -1800    0.0  0.0
                    -0.626 -0.625 -0.3125  0.0   0.50    1.0  2.0
! MINER TCC-III-45 LT
!   214      7     -8800    -7800       -5800       -4300    -1800   0.0   0.0
!                  -0.626    -0.625      -0.3125        0.0       0.5   0.8   0.9
! TCC-III-45-RA Roller assist CCSB
!
! TCC-II-60 Miner 6000 lb pre-load
! Re-calculated
!   214      8      -22.0E3   -12.0E3  -9.0E3  -6.0E3  -3.5E3  -2.0E3  0.0
0.0
```

```
!
!
!                         Constant Contact Side Bearings
! **************************** Stucki's ******************************
!
!  ISB 9-DR ISB-9DR-B Roller assist CCSB
!   214      9     -13500  -13500 -11500  -5500** -4000 -2500** -1000**  0.0
0.0
!                  -0.35** -0.25  -0.1563 -0.0625  0.0** 0.125*  0.2813**
0.4375  1.0
!  ISB 9-DR ISB-9DR-B Roller assist CCSB
!   214      10    -19500   -9500  -8000   -5000** -4500  -4000** -3000** -2000**
-1000**  0.0
!                  -0.2600  -0.25  -0.1875 -0.0313** 0.0*  0.0313  0.1094
0.1875  0.2813  0.4375
!
!  ISB12 6000 lb pre-load (Roller Assist)
!   214      7     -1.68E4   -1.1E4**  -6.0E3**  -3.0E3**  -8.0E2** 0.0*   0.0
!                  -0.25**   -0.125**   0.0**     0.125**   0.25**  0.375
0.385
!
!  *************************** Miner's ***************************
!
! Constant contact side bearings:  Preliminary TCC3-60 Characteristic
!   214      5     -1.0E7   -1.35E4    -6.0E3** 0.0*    0.0
!                  -1.625*  -0.62*      0.0     1.09    2.0
! Constant contact side bearings MINER TCC-III-45 Long-travel w/ 4800lb
pre-load
!   214     10    -1.0E7  -1.0E4   -8.0E3  -6.0E3  -4.8E3**
!                 -4.0E3  -3.0E3   -2.0E3   0.0     0.0
!                 -1.62   -0.62    -0.42   -0.17    0.0
!                  0.13    0.28     0.46    0.93    1.83
! Constant contact side bearings Stucki 656-CRH w/ 6000lb pre-load
!   214     11    -1.0E7   -16600   -10900   -6300   -4350**
!                 -2800**   -1700**   -800**  -300**   0.0   0.0
!                 -1.25**  -0.25**  -0.125**  0.0** 0.0625
!                  0.125    0.1875** 0.25**   0.3125** 0.375 1.375
! Constant contact side bearings (hypothetical) 3000lb pre-load
!   214     10    -1.0E7  -1.0E4   -8.0E3  -6.0E3  -4.8E3
!                 -4.0E3  -3.0E3   -2.0E3** 0.0*    0.0
!                 -1.90** -0.90** -0.70** -0.45** -0.28**
!                 -0.15**  0.0**   0.18**  0.65**  1.55
!********************************* Damping
****************************************
! Low damping to ensure proper roll
!  215       3     0.0       1.0E2** 1.0E2**
!                  0.0       0.025** 1.0**
   215       3     0.0       5.0E2** 5.0E2**
                   0.0       0.025** 1.0**
!
!******************      Truck C
*************************************************
! VERTICAL SUSPENSION WITH STATIC DEFLECTIONS FOR  4 EQUIVALENT SPRINGS
!  7-D5 OUTER** 7-D6 INNER** 5-D6A INNER/INNER SPRINGS**

! FRICTION WEDGE CONTROL SPRING STIFFNESS FOR 2 EQUIVALENT SPRINGS
! ** NOTE: CALCULATIONS OF EQUIVALENT SPRINGS DO NOT ACCOUNT**
!         FOR THE PITCH MOMENT OF THE BOLSTER*****
!  7-D5 OUTER** 7-D6 INNER** 5-D6A INNER/INNER SPRINGS**

! Empty Lateral
! Lateral bolster to side frame
! 216   3    0.000E+0  6.180E+3  1.062E+5**
!            0.0000    0.5000    0.6000**
```

```
! Loaded Lateral
! Lateral bolster to side frame
  216   3     0.000E+0  8.631E+3  1.086E+522
              0.0000    0.5000    0.6000
! Pitch Stiffness and Stops Mid Tolerance is Approx2+/- 2.4 Degrees=0.042mRad
  217   3     0.0       0.0     6.40E7
              0.0       0.042   1.042
! Empty Warp
! Empty
! Truck bolster to side frame torsion spring
! 218   3     0.000E+0  2.073E+4  6.607E+522
!             0.0000    0.0300    0.0400
! Loaded Warp
! Truck bolster to side frame torsion spring
  218   3     0.000E+0  2.719E+4  6.672E+522
              0.0000    0.0300    0.0400
! Empty Vertical
! Truck Bolster to Side Frame Vertical Spring: 1/4 spring group
! 219   9    -4.962E+4 -2.462E+4 -1.624E+3 -1.226E+3 -1.168E+3  0.000E+022
0.000E+0  0.000E+0  0.000E+022
!            -3.489822 -3.389822 -0.077322 -0.014822  0.0000    0.2977
1.2352
! Loaded Vertical
! Truck Bolster to Side Frame Vertical Spring: 1/4 spring group
  219   9    -4.962E+4 -2.462E+4 -1.435E+4 -1.624E+3 -1.226E+3  0.000E+022
  0.000E+0  0.000E+0  0.000E+022
             -1.578922 -1.478922  0.0000    1.833622  1.896122  2.2086
              3.146122  3.458622  4.4586
! Empty Wedges
! Friction Wedge Control Spring Stiffness:
!  2-B353 O OUTER CONTROL22 2-B354 I INNER CONTROL COILS22

! 220   9    -5.914E+4 -9.139E+3 -2.723E+3 -2.602E+3 -2.573E+3 -1.997E+322
-1.806E+2  0.000E+0  0.000E+022
!            -3.489822 -3.389822 -0.077322 -0.014822  0.0000    0.2977
1.2352    1.5477    2.5477
! Loaded Wedges
! Friction Wedge Control Spring Stiffness:
!  2-B353 O OUTER CONTROL22 2-B354 I INNER CONTROL COILS22

  220   9    -5.914E+4 -9.139E+3 -6.275E+3 -2.723E+32-2.602E+32-1.997E+322
  1.806E+2  0.000E+0  0.000E+0
             -1.578922 -1.478922  0.0000    1.833622  1.896122  2.208622
              3.146122  3.458622  4.4586
!********************* Bearing Adapter Side Frame to2Axle
*********************
!
! Bearing2adapter stops
! 125 Ton          78 inches
! 2mRad = 0.079
! 4mRad = 0.158
! 6mRad = 0.237
!
! Left Longitudinal Stiffness with Stops
  221       3       0.0     1.0      1.E3
                    0.0     0.0468  0.0478
! Right Longitudinal Stiffness with Stops
  222       3       0.0     1.0      1.E3
                    0.0     0.0468  0.0478
! Left Lateral Stiffness with Stops
  223       3       0.0     1.0      1.E322
                    0.0     0.250   0.251
! Right Lateral Stiffness with Stops
  224       3       0.0     1.0      1.E322
```

```
!
  225       3       0.0     0.0     6.4E5
                    0.0     0.030   0.040
! Right Yaw Stiffness with Stops
  226       3       0.0     0.0     6.4E5
                    0.0     0.030   0.040
! Vertical Bearing Adapter connection with offsets
! Empty 4088
! Loaded 19126
! Empty
! 227       3      -3940        0.0        0.0
!                   0.0         0.003940   1.0
! Loaded
   227       3      -18875       0.0        0.0
                     0.0         0.018875   1.0
  228       2       0.0         1.0E3
                    0.0         1.0
! Frame brace characteristic(from Std Car: 140,0001b/in per pad set)
! 229       2       0.0     7.0E4
!                   0.0     1.0
! 230       2       0.0     1.0E2
!                   0.0     1.0
!
******************************************************************************

! <<<<<<<<<<<<<<<<<<<<<<<<< Truck D >>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>
!
! ********************** Center plate Connections ****************************
! Longitudinal and lateral rim normal stiffness and damping,
! Steel on steel, with 80 lb/in  +/-0.125 inch gap
  310       4     -1.101E3   -10.0    0.0  0.0
                  -0.126     -0.125   0.0  1.0
  311       2       0.0      1.E3
                    0.0      1.0
! Verticals Top
! Empty
! Top 1734
! Bottom 4908
! Loaded
! Top 16772
! Bottom 34983
!
! Empty Top
! 312       3      -1734     0.0          0.0
!                   0.0      0.0001734    1.0
! Empty Bottom
! Verticals Bottom
! 313       3      -4908     0.0          0.0
!                   0.0      0.0004908    1.0
! Loaded Top - Curt's original
! 312       3      -16205    0.0          0.0
!                   0.0      0.0016205    1.0
! Loaded Top - adjusted STG
  312       4      -32410        -16205     0.0        0.0
                   -0.0116205    -0.01      0.15205    1.0
! Loaded Bottom
! Verticals Bottom
            3      -32268    0.0          0.0
                    0.0      0.0032268    1.0
!
! Side Bearings
! ********************** Constant Contact Side Bearings **********************
! **************************** Miner's *****************************
```

```
! TCC-III-LT Sidebearing. Works for the RA if the gap is Roller SB is set to
go solid at -0.3125.
!   314      6       -10500    -9500     -7000    -5400    0.0        0.0
!                   -0.626    -0.625    -0.3125   0.0    1.1625     1.2625
! MINER TCC-III-45 ST
!   314      6      -6800        -5800        -4300     -1800   0.0   0.0
!                   -0.3135      -0.3125        0.0       0.5   0.8   0.9
! MINER TCC-III-45 RA  (Must turn on Roller SB when using this PWL)
!   314      5     -5800       -4300     -1800   0.0   0.0
!                  -0.3125        0.0       0.5   0.8
! TCC-III-45 Long Travels
    314      7     -8800  -7800  -5800  -4300  -1800   0.0  0.0
                   -0.626 -0.625 -0.3125  0.0   0.50   1.0  2.0
! MINER TCC-III-45 LT
!   314      7     -8800    -7800        -5800        -4300     -1800   0.0   0.0
!                  -0.626   -0.625       -0.3125        0.0       0.5   0.8
! TCC-III-45-RA Roller assist CCSB
!
! TCC-II-60 Miner 6000 lb pre-load
! Re-calculated
!   314      8      -22.0E3   -12.0E3  -9.0E3  -6.0E3  -3.5E3  -2.0E3  0.0
0.0
!                   -0.61     -0.6     -0.4    0.0     0.4     0.70   0.8  1.0
!
! ********************** Constant Contact Side Bearings *********************
! **************************** Stucki's ****************************
!
!  ISB 9-DR ISB-9DR-B Roller assist CCSB
!   314      9     -13500  -13500 -11500  -5500   -4000 -2500   -1000    0.0
0.0
!                  -0.35   -0.25  -0.1563 -0.0625  0.0   0.125   0.2813
0.4375  1.0
!  ISB 9-DR ISB-9DR-B Roller assist CCSB
!   314     10    -19500   -9500  -8000   -5000   -4500  -4000   -3000   -2000
-1000    0.0
!                 -0.2600  -0.25  -0.1875 -0.0313   0.0   0.0313  0.1094
0.1875  0.2813  0.4375
!
!  ISB12 6000 lb pre-load (Roller Assist)
!   314      7    -1.68E4   -1.1E4    -6.0E3    -3.0E3    -8.0E2   0.0    0.0
!                 -0.25     -0.125     0.0       0.125     0.25    0.375
0.385
!
!  **************************** Miner's ****************************
!
! Constant contact side bearings:  Preliminary TCC3-60 Characteristic
!   314      5     -1.0E7   -1.35E4    -6.0E3   0.0     0.0
!                  -1.625   -0.62        0.0    1.09    2.0
! Constant contact side bearings MINER TCC-III-45 Long-travel w/ 4800lb
pre-load
!   314     10    -1.0E7  -1.0E4  -8.0E3  -6.0E3  -4.8E3
!                 -4.0E3  -3.0E3  -2.0E3   0.0     0.0
!                 -1.62   -0.62   -0.42   -0.17    0.0
!                  0.13    0.28    0.46    0.93    1.83
! Constant contact side bearings Stucki 656-CRH w/ 6000lb pre-load
!   314     11    -1.0E7   -16600   -10900   -6300   -4350
!                 -2800     -1700     -800    -300     0.0   0.0
!                 -1.25    -0.25    -0.125    0.0   0.0625
!                  0.125    0.1875   0.25     0.3125   0.375 1.375
! Constant contact side bearings (hypothetical) 3000lb pre-load
!   314     10    -1.0E7  -1.0E4  -8.0E3  -6.0E3  -4.8E3
!                 -4.0E3  -3.0E3  -2.0E3   0.0     0.0
!                 -1.90   -0.90   -0.70   -0.45   -0.28
!                 -0.15    0.0     0.18    0.65    1.55
```

```
!*******************************
****************************************
! Low damping to ensure proper roll
!  315       3     0.0       1.0E2   1.0E2
!                  0.0       0.025   1.0
   315       3     0.0       5.0E2   5.0E2
                   0.0       0.025   1.0
!
!******************     Truck D
***********************************************
! VERTICAL SUSPENSION WITH STATIC DEFLECTIONS FOR  4 EQUIVALENT SPRINGS
!  7-D5 OUTER00 7-D6 INNER00 5-D6A INNER/INNER SPRINGS00

! FRICTION WEDGE CONTROL SPRING STIFFNESS FOR 2 EQUIVALENT SPRINGS
! ** NOTE: CALCULATIONS OF EQUIVALENT SPRINGS DO NOT ACCOUNT00
!          FOR THE PITCH MOMENT OF THE BOLSTER0**00
!  7-D5 OUTER   7-D6 INNER   5-D6A INNER/INNER SPRINGS

! Empty Lateral
! Lateral bolster to side frame
! 316   3     0.000E+0  6.180E+3  1.062E+500
!             0.0000    0.5000    0.6000
! Loaded Lateral
! Lateral bolster to side frame
  316   3     0.000E+0  8.631E+3  1.086E+500
              0.0000    0.5000    0.6000
! Pitch Stiffness and Stops Mid Tolerance is Approx0+/- 2.4 Degrees=0.042mRad
  317   3     0.0       0.0     6.40E7
              0.0       0.042   1.042
! Empty Warp
! Empty
! Truck bolster to side frame torsion spring
! 318   3     0.000E+0  2.073E+4  6.607E+500
!             0.0000    0.0300    0.0400
! Loaded Warp
! Truck bolster to side frame torsion spring
  318   3     0.000E+0  2.719E+4  6.672E+500
              0.0000    0.0300    0.0400
! Empty Vertical
! Truck Bolster to Side Frame Vertical Spring: 1/4 spring group
! 319   9    -4.962E+4 -2.462E+4 -1.624E+3 -1.226E+3 -1.168E+3  0.000E+000
0.000E+0  0.000E+0  0.000E+000
!            -3.489800 -3.389800 -0.077300 -0.014800  0.0000    0.2977
1.2352    1.5477    2.5477
! Loaded Vertical
! Truck Bolster to Side Frame Vertical Spring: 1/4 spring group
  319   9    -4.962E+4 -2.462E+4 -1.435E+4 -1.624E+3 -1.226E+3  0.000E+000
  0.000E+0  0.000E+0  0.000E+000
             -1.578900 -1.478900  0.0000    1.8336    1.8961    2.2086
             3.146100  3.458600  4.4586
! Empty Wedges
! Friction Wedge Control Spring Stiffness:
!  2-B353 O OUTER CONTROL00 2-B354 I INNER CONTROL COILS00

! 320   9    -5.914E+4 -9.139E+30-2.723E+3 -2.602E+3 -2.573E+3 -1.997E+300
-1.806E+2000.000E+0  0.000E+000
!            -3.489800 -3.389800 -0.077300 -0.014800  0.0000    0.2977
1.2352    1.5477    2.5477
! Loaded Wedges
! Friction Wedge Control Spring Stiffness:
!  2-B353 O OUTER CONTROL00 2-B354 I INNER CONTROL COILS00

  320   9    -5.914E+4 -9.139E+3 -6.275E+3 -2.723E+3 -2.602E+3 -1.997E+3 -
  1.806E+2  0.000E+0  0.000E+000
```

```
            -1.5789   -1.4789    0.0000    1.8336    1.8961    2.2086
            3.1461    3.4586    4.4586
!******************** Bearing Adapter Side Frame to Axle
********************
!
! Bearing adapter stops
! 125 Ton 39 * 2= 78 inches
! 2mRad = 0.079
! 4mRad = 0.158
! 6mRad = 0.237
!
! Left Longitudinal Stiffness with Stops
  321      3      0.0    1.0      1.E3
                  0.0    0.0468  0.0478
! Right Longitudinal Stiffness with Stops
  322      3      0.0    1.0      1.E3
                  0.0    0.0468  0.0478
! Left Lateral Stiffness with Stops
  323      3      0.0    1.0      1.E3
                  0.0    0.250   0.251
! Right Lateral Stiffness with Stops
  324      3      0.0    1.0      1.E3
                  0.0    0.250   0.251
! Left Yaw Stiffness with Stops
  325      3      0.0    0.0      6.4E5
                  0.0    0.030   0.040
! Right Yaw Stiffness with Stops
  326      3      0.0    0.0      6.4E5
                  0.0    0.030   0.040
! Vertical Bearing Adapter connection with offsets
! Empty 4088
! Loaded 19126
! Empty
! 327      3     -3695       0.0        0.0
!                 0.0        0.003695  1.0
! Loaded
           3     -18785      0.0        0.0
                  0.0        0.018785  1.0
  328      2      0.0        1.0E3
                  0.0        1.0
! Frame brace characteristic(from Std Car: 140,000lb/in per pad set)
! 329      2      0.0    7.0E4
!                 0.0    1.0
! 330      2      0.0    1.0E2
!                 0.0    1.0
!
******************************************************************************

! <<<<<<<<<<<<<<<<<<<<<<<<<< Truck E >>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>
!
! ******************** Center plate Connections **************************
! Longitudinal and lateral rim normal stiffness and damping,
! Steel on steel, with 80 lb/in  +/-0.125 inch gap
  410      4    -1.101E3   -10.0   0.0  0.0
                  -0.126   -0.125  0.0  1.0
  411      2       0.0      1.E3
                   0.0      1.0
! Verticals Top
! Empty
! Top 1734
! Bottom 4908
! Loaded
! Top 16772
! Bottom 34983
```

```
!
!
! 412      3      -1734     0.0         0.0
!                  0.0      0.0001734   1.0
! Empty Bottom
! Verticals Bottom
! 413      3      -4908     0.0         0.0
!                  0.0      0.0004908   1.0
! Loaded Top - Curt's original
! 412      3      -16060    0.0         0.0
!                  0.0      0.0016060   1.0
! Loaded Top - Adjusted STG
  412      4      -32120       -16060    0.0        0.0
                  -0.0116060   -0.01     0.15060    1.0
! Loaded Bottom
! Verticals Bottom
  413      3      -32260    0.0         0.0
                   0.0      0.0032260   1.0
!
! Side Bearings
! ********************** Constant Contact Side Bearings *********************
! **************************** Miner's ****************************
! TCC-III-LT Sidebearing. Works for the RA if the gap is Roller SB is set to
go solid at -0.3125.
!   414      6       -10500    -9500     -7000    -5400    0.0        0.0
!                   -0.626    -0.625    -0.3125   0.0     1.1625     1.2625
! MINER TCC-III-45 ST
!   414      6      -6800         -5800        -4300    -1800   0.0   0.0
!                   -0.3135       -0.3125        0.0       0.5   0.8   0.9
! MINER TCC-III-45 RA  (Must turn on Roller SB when using this PWL)
!   414      5      -5800       -4300     -1800   0.0   0.0
!                   -0.3125        0.0       0.5   0.8   0.9
! TCC-III-45 Long Travels
    414      7    -8800  -7800  -5800  -4300  -1800   0.0  0.0
                  -0.626 -0.625 -0.3125  0.0   0.50   1.0  2.0
! MINER TCC-III-45 LT
!   414      7    -8800    -7800        -5800       -4300    -1800   0.0   0.0
!                 -0.626    -0.625       -0.3125       0.0      0.5   0.8   0.9
! TCC-III-45-RA Roller assist CCSB
!
! TCC-II-60 Miner 6000 lb pre-load
! Re-calculated
!   414      8      -22.0E3   -12.0E3  -9.0E3  -6.0E3  -3.5E3  -2.0E3  0.0
0.0
!                   -0.61     -0.6     -0.4    0.0     0.4     0.70   0.8  1.0
!
! ********************** Constant Contact Side Bearings *********************
! **************************** Stucki's ****************************
!
!  ISB 9-DR ISB-9DR-B Roller assist CCSB
!   414      9     -13500  -13500 -11500  -5500   -4000 -2500   -1000    0.0
0.0
!                  -0.35   -0.25  -0.1563 -0.0625  0.0   0.125   0.2813
0.4375  1.0
!  ISB 9-DR ISB-9DR-B Roller assist CCSB
!   414      10    -19500  -9500  -8000   -5000   -4500  -4000   -3000   -2000
-1000    0.0
!                  -0.2600  -0.25  -0.1875 -0.0313   0.0   0.0313  0.1094
0.1875  0.2813  0.4375
!
!  ISB12 6000 lb pre-load (Roller Assist)
!   414      7    -1.68E4   -1.1E4    -6.0E3    -3.0E3    -8.0E2   0.0    0.0
!                 -0.25     -0.125     0.0       0.125     0.25    0.375
```

```
!
!                               Miner's0*****************************00
!
! Constant contact side bearings:  Preliminary TCC3-60 Characteristic
!   414      5     -1.0E7   -1.35E400   -6.0E3   0.0      0.0
!                  -1.62500 -0.6200     0.0      1.09     2.0
! Constant contact side bearings MINER TCC-III-45 Long-travel w/ 4800lb
pre-load
!00 41400   10    -1.0E7  -1.0E4  -8.0E3  -6.0E3  -4.8E300
!                 -4.0E3  -3.0E3  -2.0E3   0.0     0.0
!                 -1.62   -0.62   -0.42   -0.17    0.0
!                  0.13    0.28    0.46    0.93    1.83
! Constant contact side bearings Stucki 656-CRH w/ 6000lb pre-load
!   414     11    -1.0E7   -16600   -10900   -6300   -435000
!                 -280000   -170000   -80000  -30000   0.0   0.0
!                 -1.2500  -0.2500  -0.12500  0.000 0.0625
!                  0.125    0.187500 0.2500   0.312500 0.375 1.375
! Constant contact side bearings (hypothetical) 3000lb pre-load
!   414     10    -1.0E7  -1.0E4  -8.0E3  -6.0E3  -4.8E3
!                 -4.0E3  -3.0E3  -2.0E300 0.00    0.0
!                 -1.9000 -0.9000 -0.7000 -0.4500 -0.2800
!                 -0.1500  0.000   0.1800  0.6500  1.55
!******************************* Damping
****************************************
! Low damping to ensure proper roll
!  415       3     0.0       1.0E200 1.0E20
!                  0.0       0.025   1.0
   415       3     0.0       5.0E2   5.0E2
                   0.0       0.025   1.0
!
!******************     Truck D
*************************************************
! VERTICAL SUSPENSION WITH STATIC DEFLECTIONS FOR  4 EQUIVALENT SPRINGS
!  7-D5 OUTER00 7-D6 INNER00 5-D6A INNER/INNER SPRINGS00

! FRICTION WEDGE CONTROL SPRING STIFFNESS FOR 2 EQUIVALENT SPRINGS
! ** NOTE: CALCULATIONS OF EQUIVALENT SPRINGS DO NOT ACCOUNT00
!          FOR THE PITCH MOMENT OF THE BOLSTER0**00
!  7-D5 OUTER   7-D6 INNER   5-D6A INNER/INNER SPRINGS

! Empty Lateral
! Lateral bolster to side frame
! 416   3    0.000E+0  6.180E+3  1.062E+500
!            0.0000    0.5000    0.6000
! Loaded Lateral
! Lateral bolster to side frame
  416   3    0.000E+0  8.631E+3  1.086E+500
             0.0000    0.5000    0.6000
! Pitch Stiffness and Stops Mid Tolerance is Approx0+/- 2.4 Degrees=0.042mRad
  417   3    0.0       0.0     6.40E7
             0.0       0.042   1.042
! Empty Warp
! Empty
! Truck bolster to side frame torsion spring
! 418   3    0.000E+0  2.073E+4  6.607E+500
!            0.0000    0.0300    0.0400
! Loaded Warp
! Truck bolster to side frame torsion spring
  418   3    0.000E+0  2.719E+4  6.672E+500
             0.0000    0.0300    0.0400
! Empty Vertical
! Truck Bolster to Side Frame Vertical Spring: 1/4 spring group
! 419   9   -4.962E+4 -2.462E+4 -1.624E+3 -1.226E+3 -1.168E+3  0.000E+0
0.000E+0  0.000E+0  0.000E+000
```

```
!
! Loaded Vertical
! Truck Bolster to Side Frame Vertical Spring: 1/4 spring group
  419   9   -4.962E+4 -2.462E+4 -1.435E+4 -1.624E+3 -1.226E+3  0.000E+0
  0.000E+0  0.000E+0  0.000E+0
            -1.5789   -1.4789    0.0000    1.8336    1.8961    2.2086
            3.1461    3.4586    4.4586
! Empty Wedges
! Friction Wedge Control Spring Stiffness:
!  2-B353 O OUTER CONTROL   2-B354 I INNER CONTROL COILS

! 420   9   -5.914E+4 -9.139E+3 -2.723E+3 -2.602E+3 -2.573E+3 -1.997E+3
-1.806E+2  0.000E+0  0.000E+0
!           -3.4898   -3.3898   -0.0773   -0.0148    0.0000    0.2977
1.2352    1.5477    2.5477
! Loaded Wedges
! Friction Wedge Control Spring Stiffness:
!  2-B353 O OUTER CONTROL   2-B354 I INNER CONTROL COILS

  420   9   -5.914E+4 -9.139E+3 -6.275E+3 -2.723E+3 -2.602E+3 -1.997E+3 -
  1.806E+2  0.000E+0  0.000E+0
            -1.5789   -1.4789    0.0000    1.8336    1.8961    2.2086
            3.1461    3.4586    4.4586
!********************* Bearing Adapter Side Frame to Axle
*********************
!
! Bearing adapter stops
! 125 Ton 39 * 2= 78 inches
! 2mRad = 0.079
! 4mRad = 0.158
! 6mRad = 0.237
!
! Left Longitudinal Stiffness with Stops
  421      3       0.0     1.0      1.E3
                   0.0     0.0468   0.0478
! Right Longitudinal Stiffness with Stops
  422      3       0.0     1.0      1.E3
                   0.0     0.0468   0.0478
! Left Lateral Stiffness with Stops
  423      3       0.0     1.0      1.E3
                   0.0     0.250    0.251
! Right Lateral Stiffness with Stops
  424      3       0.0     1.0      1.E3
                   0.0     0.250    0.251
! Left Yaw Stiffness with Stops
  425      3       0.0     0.0      6.4E5
                   0.0     0.030    0.040
! Right Yaw Stiffness with Stops
  426      3       0.0     0.0      6.4E5
                   0.0     0.030    0.040
! Vertical Bearing Adapter connection with offsets
! Empty 4088
! Loaded 19126
! Empty
! 427      3      -4088        0.0        0.0
!                  0.0         0.004088   1.0
! Loaded
  427      3      -18785       0.0        0.0
                   0.0         0.018785   1.0
  428      2       0.0         1.0E3
                   0.0         1.0
! Frame brace characteristic(from Std Car: 140,000lb/in per pad set)
! 429      2       0.0     7.0E4
```

```
!
!
!
!
********************************************************************************

! <<<<<<<<<<<<<<<<<<<<<<<<<<< Truck E >>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>
!
! ********************** Center plate Connections ***************************
! Longitudinal and lateral rim normal stiffness and damping,
! Steel on steel, with 80 lb/in  +/-0.125 inch gap
  510      4    -1.101E3   -10.0   0.0  0.0
                 -0.126   -0.125  0.0  1.0
  511      2       0.0      1.E3
                   0.0      1.0
! Verticals Top
! Empty
! Top 1734
! Bottom 4908
! Loaded
! Top 16772
! Bottom 34983
!
! Empty Top
! 512      3      -1734     0.0        0.0
!                  0.0      0.0001734  1.0
! Empty Bottom
! Verticals Bottom
! 513      3      -4908     0.0        0.0
!                  0.0      0.0004908  1.0
! Loaded Top - Curt's original
! 512      3      -11060    0.0        0.0
!                  0.0      0.0011060  1.0
! Loaded Top - Adjusted STG
  512      4      -22120        -11060    0.0        0.0
                  -0.0111060    -0.01     0.1006     1.0
! Loaded Bottom
! Verticals Bottom
  513      3      -32400    0.0        0.0
                   0.0      0.0032400  1.0
!
! Side Bearings
! ********************** Constant Contact Side Bearings *********************
! **************************** Miner's ****************************
! TCC-III-LT Sidebearing. Works for the RA if the gap is Roller SB is set to
go solid at -0.3125.
!   514      6       -10500    -9500     -7000    -5400     0.0        0.0
!                   -0.626    -0.625    -0.3125   0.0     1.1625     1.2625
! MINER TCC-III-45 ST
!   514      6      -6800         -5800        -4300     -1800    0.0    0.0
!                   -0.3135       -0.3125          0.0       0.5    0.8    0.9
! MINER TCC-III-45 RA  (Must turn on Roller SB when using this PWL)
!   514      5     -5800        -4300     -1800    0.0    0.0
!                  -0.3125         0.0       0.5    0.8    0.9
! TCC-III-45 Long Travels
    514      7     -8800  -7800  -5800  -4300  -1800   0.0  0.0
                   -0.626 -0.625 -0.3125  0.0   0.50   1.0  2.0
! MINER TCC-III-45 LT
!   514      7     -8800    -7800       -5800       -4300     -1800   0.0   0.0
!                  -0.626    -0.625      -0.3125        0.0       0.5   0.8   0.9
! TCC-III-45-RA Roller assist CCSB
!
! TCC-II-60 Miner 6000 lb pre-load
! Re-calculated
```

```
!
0.0
!                   -0.6100   -0.600   -0.400  0.0     0.4     0.70   0.8  1.0
!
! ********************** Constant Contact Side Bearings **********************
! **************************** Stucki's ***************************
!
!  ISB 9-DR ISB-9DR-B Roller assist CCSB
!   514      9     -13500  -13500 -11500  -550000 -4000 -250000 -100000  0.0
0.0
!                  -0.3500 -0.25  -0.1563 -0.0625  0.000 0.1250  0.281300
0.4375  1.0
!  ISB 9-DR ISB-9DR-B Roller assist CCSB
!   514      10    -19500   -9500  -8000   -500000 -4500  -400000 -300000 -200000
-100000  0.0
!                 -0.2600  -0.25  -0.1875 -0.031300 0.00  0.0313  0.1094
0.1875  0.2813  0.4375
!
!  ISB12 6000 lb pre-load (Roller Assist)
!   514      7    -1.68E4   -1.1E400  -6.0E300  -3.0E300  -8.0E200 0.00   0.0
!                 -0.2500   -0.12500   0.000     0.12500   0.2500  0.375
0.385
!
!  ****************************0Miner's0****************************00
!
! Constant contact side bearings:  Preliminary TCC3-60 Characteristic
!   514      5     -1.0E7   -1.35E400  -6.0E300 0.00    0.0
!                  -1.62500 -0.6200     0.000   1.09    2.0
! Constant contact side bearings MINER TCC-III-45 Long-travel w/ 4800lb
pre-load
!   514     10    -1.0E7  -1.0E4  -8.0E3  -6.0E3  -4.8E3
!                 -4.0E3  -3.0E3  -2.0E3   0.0     0.0
!                 -1.62   -0.62   -0.42   -0.17    0.0
!                  0.13    0.28    0.46    0.93    1.83
! Constant contact side bearings Stucki 656-CRH w/ 6000lb pre-load
!   514     11    -1.0E7    -16600    -10900    -6300    -435000
!                 -280000    -170000    -80000   -30000    0.0   0.0
!                 -1.2500  -0.2500   -0.12500  0.000 0.0625
!                  0.12500  0.187500 0.2500   0.312500 0.375 1.375
! Constant contact side bearings (hypothetical) 3000lb pre-load
!   514     10    -1.0E7  -1.0E4  -8.0E3  -6.0E3  -4.8E3
!                 -4.0E3  -3.0E3  -2.0E300 0.00    0.0
!                 -1.9000 -0.9000 -0.7000 -0.4500 -0.2800
!                 -0.1500  0.000   0.1800  0.6500  1.55
!******************************** Damping
******************************************
! Low damping to ensure proper roll
!  515       3     0.0       1.0E200 1.0E200
!                  0.0       0.025   1.000
   515       3     0.0       5.0E2   5.0E200
                   0.0       0.025   1.000
!
!******************       Truck D
**************************************************
! VERTICAL SUSPENSION WITH STATIC DEFLECTIONS FOR  4 EQUIVALENT SPRINGS
!  7-D5 OUTER00 7-D6 INNER00 5-D6A INNER/INNER SPRINGS00

! FRICTION WEDGE CONTROL SPRING STIFFNESS FOR 2 EQUIVALENT SPRINGS
! ** NOTE: CALCULATIONS OF EQUIVALENT SPRINGS DO NOT ACCOUNT00
!          FOR THE PITCH MOMENT OF THE BOLSTER0**00
!  7-D5 OUTER00 7-D6 INNER00 5-D6A INNER/INNER SPRINGS00

! Empty Lateral
! Lateral bolster to side frame
```

```
! 516   3    0.000E+0  6.180E+3  1.062E+5
!              0.0000    0.5000    0.6000
! Loaded Lateral
! Lateral bolster to side frame
  516   3    0.000E+0  8.631E+3  1.086E+5
               0.0000    0.5000    0.6000
! Pitch Stiffness and Stops Mid Tolerance is Approx +/- 2.4 Degrees=0.042mRad
  517   3    0.0       0.0     6.40E7
             0.0       0.042   1.042
! Empty Warp
! Empty
! Truck bolster to side frame torsion spring
! 518   3    0.000E+0  2.073E+4  6.607E+5
!            0.0000    0.0300    0.0400
! Loaded Warp
! Truck bolster to side frame torsion spring
  518   3    0.000E+0  2.719E+4  6.672E+5
             0.0000    0.0300    0.0400
! Empty Vertical
! Truck Bolster to Side Frame Vertical Spring: 1/4 spring group
! 519   9   -4.962E+4 -2.462E+4 -1.624E+3 -1.226E+3 -1.168E+3  0.000E+0
0.000E+0  0.000E+0  0.000E+0
!           -3.4898   -3.3898   -0.0773   -0.0148    0.0000    0.2977
1.2352    1.5477    2.5477
! Loaded Vertical
! Truck Bolster to Side Frame Vertical Spring: 1/4 spring group
  519   9   -4.962E+4 -2.462E+4 -1.435E+4 -1.624E+3 -1.226E+3  0.000E+0
  0.000E+0  0.000E+0  0.000E+0
            -1.5789   -1.4789    0.0000    1.8336    1.8961    2.2086
            3.1461    3.4586    4.4586
! Empty Wedges
! Friction Wedge Control Spring Stiffness:
!  2-B353 O OUTER CONTROL   2-B354 I INNER CONTROL COILS

! 520   9   -5.914E+4 -9.139E+3 -2.723E+3 -2.602E+3 -2.573E+3 -1.997E+3
-1.806E+2  0.000E+0  0.000E+0
!           -3.4898   -3.3898   -0.0773   -0.0148    0.0000    0.2977
1.2352              2.5477
! Loaded Wedges
! Friction Wedge Control Spring Stiffness:
!  2-B353 O OUTER CONTROL   2-B354 I INNER CONTROL COILS

  520   9   -5.914E+4 -9.139E+3 -6.275E+3 -2.723E+3 -2.602E+3 -1.997E+3 -
  1.806E+2  0.000E+0  0.000E+0
            -1.5789   -1.4789    0.0000    1.8336    1.8961    2.2086
            3.1461    3.4586    4.4586
!********************* Bearing Adapter Side Frame to Axle
*********************
!
! Bearing adapter stops
! 125 Ton 39 * 2= 78 inches
! 2mRad = 0.079
! 4mRad = 0.158
! 6mRad = 0.237
!
! Left Longitudinal Stiffness with Stops
  521      3      0.0    1.0     1.E3
                  0.0    0.0468  0.0478
! Right Longitudinal Stiffness with Stops
  522      3      0.0    1.0     1.E3
                  0.0    0.0468  0.0478
! Left Lateral Stiffness with Stops
  523      3      0.0    1.0     1.E3
                  0.0    0.250   0.251
```

```
!
  524      3      0.0    1.0     1.E300
                  0.0    0.250   0.251
! Left Yaw Stiffness with Stops
  525      3      0.0    0.0     6.4E5
                  0.0    0.030   0.040
! Right Yaw Stiffness with Stops
  526      3      0.0    0.0     6.4E500
                  0.0    0.030   0.040
! Vertical Bearing Adapter connection with offsets
! Empty 4088
! Loaded 19126
! Empty
! 527      3     -408800     0.0        0.0
!                 0.000      0.004088  1.0
! Loaded
  527      3     -1887000    0.0        0.0
                  0.000      0.018870  1.0
  528      2      0.000      1.0E300
                  0.000      1.000
! Frame brace characteristic(from Std Car: 140,000lb/in per pad set)
! 529      2      0.0    7.0E4
!                 0.0    1.0
! 530      2      0.0    1.0E20
!                 0.0    1.00
!
******************************************************************************

! <<<<<<<<<<<<<<<<<<<<<<<<< Truck A >>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>
!
! ********************** Center plate Connections0****************************
! Longitudinal and lateral rim normal stiffness and damping,
! Steel on steel, with 80 lb/in  +/-0.125 inch gap
  610      4    -1.101E3   -10.0   0.0  0.0
                 -0.1260  -0.125   0.0  1.000
  611      2      0.0       1.E30
                  0.0       1.00
! Verticals
! Empty 2000 using 9000 at CCSB's
! Loaded 17038 using 9000 at CCSB's
!Empty
!0061200   3      -200000   0.0       0.0
!                  0.000    0.0002      1.0
!Loaded00
  61200    3      -1668400  0.0        0.0
                   0.0      0.0016685 1.0
! 113 not used
! 113 not used
! Side Bearings
! ********************** Constant Contact Side Bearings0*********************
! ***************************0Miner's0****************************00
! TCC-III-LT Sidebearing. Works for the RA if the gap is Roller SB is set to
go solid at -0.3125.
!   614      6       -10500    -9500     -7000   -540000  0.0        0.0
!                   -0.62600  -0.62500  -0.312500 0.00   1.1625     1.2625
! MINER TCC-III-45 ST
!   614      6      -680000      -580000      -430000  -180000 0.00  0.0
!                   -0.313500    -0.312500      0.0      0.5   0.8   0.9
! MINER TCC-III-45 RA  (Must turn on Roller SB when using this PWL)
!   614      5     -5800       -430000  -180000 0.0    0.0
!                  -0.312500      0.0      0.5   0.8   0.9
! TCC-III-45 Long Travels
   614      7    -8800  -7800  -5800  -430000-180000 0.0  0.00
                  -0.626 -0.625 -0.3125  0.000 0.5000 1.0  2.00
```

```
!
!   614      7    -880000  -780000     -580000     -430000  -180000 0.00  0.0
!                 -0.62600  -0.62500    -0.312500     0.0      0.5   0.8   0.9
! TCC-III-45-RA Roller assist CCSB
!
! TCC-II-60 Miner 6000 lb pre-load
! Re-calculated
!   614      8      -22.0E3   -12.0E3  -9.0E3  -6.0E3  -3.5E3  -2.0E3  0.000
0.0
!                   -0.6100   -0.600   -0.400  0.0     0.4     0.70   0.8  1.0
!
! ********************** Constant Contact Side Bearings **********************
! ***************************** Stucki's *****************************00
!
!  ISB 9-DR ISB-9DR-B Roller assist CCSB00
!   614      9     -13500  -13500 -11500  -550000 -4000 -250000 -100000  0.0
0.0
!                  -0.3500 -0.25  -0.1563 -0.0625  0.000 0.1250  0.281300
0.4375  1.0
!  ISB 9-DR0ISB-9DR-B Roller assist CCSB0
!   614     10    -1950000 -9500  -800000 -500000 -450000-400000 -300000 -200000
-100000  0.0
!                 -0.2600  -0.25  -0.18750-0.031300 0.000 0.0313000.109400
0.1875  0.2813  0.4375
!
!  ISB12 6000 lb pre-load (Roller Assist)
!   614      7    -1.68E4   -1.1E400  -6.0E300  -3.0E300  -8.0E200 0.00   0.0
!                 -0.2500   -0.12500   0.000     0.12500   0.2500  0.375
0.385
!
!  *****************************0Miner's0*****************************00
!
! Constant contact side bearings:  Preliminary TCC3-60 Characteristic
!   614      5     -1.0E7   -1.35E400  -6.0E300 0.00    0.0
!                  -1.62500 -0.6200     0.000   1.09    2.0
! Constant contact side bearings MINER TCC-III-45 Long-travel w/ 4800lb
pre-load
!   614     10    -1.0E7  -1.0E4  -8.0E3  -6.0E3  -4.8E3
!                 -4.0E3  -3.0E3  -2.0E3   0.0     0.0
!                 -1.62   -0.62   -0.42   -0.17    0.0
!                  0.13    0.28    0.46    0.93    1.83
! Constant contact side bearings Stucki 656-CRH w/ 6000lb pre-load
!   614     11    -1.0E7   -16600   -10900   -6300   -435000
!                 -280000   -170000   -80000  -30000   0.0   0.0
!                 -1.2500  -0.2500  -0.12500  0.000 0.0625
!                  0.12500  0.187500 0.2500   0.312500 0.375 1.375
! Constant contact side bearings (hypothetical) 3000lb pre-load
!   614     10    -1.0E7  -1.0E4  -8.0E3  -6.0E3  -4.8E3
!                 -4.0E3  -3.0E3  -2.0E300 0.00    0.0
!                 -1.9000 -0.9000 -0.7000 -0.4500 -0.2800
!                 -0.1500  0.000   0.1800  0.6500  1.5500
!******************************** Damping
****************************************
! Low damping to ensure proper roll
!  615       3     0.0       1.0E200 1.0E200
!                  0.0       0.02500 1.000
   615        3    0.0       5.0E200 5.0E200
                   0.0       0.02500 1.000
!
! Truck B *************************************************00
!
! VERTICAL SUSPENSION WITH STATIC DEFLECTIONS FOR  4 EQUIVALENT SPRINGS
!  7-D5 OUTER   3-D6 INNER SPRINGS00
! FRICTION WEDGE CONTROL SPRING STIFFNESS FOR 2 EQUIVALENT SPRINGS00
```

```
! Right Yaw Stiffness with Stops
  626      3      0.0     0.0      6.4E5
                  0.0     0.030    0.040
! Verticals
! Empty 2553
! Loaded 10072
! Vertical Bearing Adapter connection with offsets
!Empty
! 627      3     -2553        0.0       0.0
!                 0.0         0.002553  1.0
!Loaded
  627      3     -9850        0.0       0.0
                  0.0         0.009850  1.0
           2      0.0         1.0E3
                              1.0
! Frame brace characteristic(from Std Car: 140,000lb/in per pad set)
!          2      0.0     7.0E4
!                 0.0     1.0
! 630      2      0.0     1.0E2
!                 0.0     1.0
!
```

```
System file (.SYS) for NUCARS Version 2005
=============================================

\SYSTEM TITLE
Equalizer beam truck, bi-level car

            Description                 Wt/item   Wt/Truck
                                          (lb)       (lb)

            Carbody                     109000     109000
            Truck frame                  7007       7007
            Truck bolster                3204       3204
            Equalizer beam               1055       2110
            Axle Assembly                4290       8580

\BODY DATA
  15
! ** Car body0**
   1    'Car Body00      '          -408.0000     0.0       87
          6  1 2 3 4 5 6             282.3200     1.1024E6  2.5206E7  2.4851E7
   2     'AirBag Ld0'               -51.000       0.0       38.2
          5    1 2 3 4 6              0.362600   1.70e2   0.0      1.070e200
   3     'AirBag Trl'               -765.000      0.0       38.2
         5    1 2 3 4 6               0.36260    1.70e2   0.0      1.070e200
!
! ** Truck A **
!
 101    'Bolster A       '           -51.000     0.0       23.9
          6     1 2 3 4 5 6           8.29900    7.4E03   659.600      7.6E03
 102    'Truck Frame A   '           -51.000     0.0       28.7
          6     1 2 3 4 5 6           18.14800   2.72E0400 3.79E040  5.53E04
 103    'Eqlizer A Left  '           -51.000    39.5       14.2
          6     1 2 3 4 5 6           2.7300   145.0       23.45E02  22.03E02
 104    'Eqlizer A Right0'           -51.000               14.2
          6     1 2 3 4 5 6           2.7300   145.000     23.45E02  22.03E02
 105    'Axle Number 1   '            0.000     0.0        18.0
          5     1 2 3 4   6           11.11100  10.9E03    12.01E02  10.9E03
 106    'Axle Number 2   '          -102.000    0.0        18.0
          5     1 2 3 4   6           11.11100  10.9E03    12.01E02  10.9E03
! ** Truck B **
 201    'Bolster B       '          -765.000     0.0       23.9
          6     1 2 3 4 5 6           8.299      7.4E03   659.600      7.6E03
 202    'Truck Frame B   '          -765.000     0.0       28.7
          6     1 2 3 4 5 6           18.14800   2.72E0400 3.79E0400 5.53E040
 203    'Eqlizer B Left  '          -765.000               14.2
          6     1 2     5 6           2.73     145.0       23.45E02  22.03E02
        'Eqlizer B Right '          -765.000   -39.500     14.2
          6     1 2 3 4 5 6           2.73     145.000     23.45E02  22.03E02
 205    'Axle Number 3   '          -714.000    0.0        18.0
          5     1 2 3 4   6           11.111    10.9E03    12.01E02  10.9E03
 206    'Axle Number 4   '          -816.000    0.0        18.0
          5     1 2 3 4   6           11.11100  10.9E03    12.01E02  10.9E03
```

Give the number of connections, then for each, identify a name in single quotes up to 20 characters, a position relative to the chosen datum, numbers for the bodies at each end, 0 for an earth in local track coords., a number indicating the degree of freedom, translational 1,2,3 or rotational 4,5,6, in x,y,z resp., including 2 for lateral wheel motion, and the type:

1 - parallel pair of spring and damper characteristics
2 - series pair of spring and damper characteristics
3 - device with hysteresis between 2 PWL characteristics, e.g. carriage0 spring or load sensitive suspension
4 - lateral/longitudinal suspension of the wheel on rail

```
    5 - connection force as a history of the distance moved
and the identification number for each of type 1, 2 and 3, the axle number
for type 4, input function number for type 5.

Note - single characteristics are treated as parallel pairs with the
       missing characteristic set to zero in the subsequent table.

 Conn # ' 15 CHARACTER  ' Type Body 1 & 2  Posn in X, Y, & Z   DoF No.
-----------------------------------------------------------------------------
\CONNECTION DATA

!
!Lead Truck
!Carbody to Airbag connections
!2point suspension
  2101  'LdCBtoAirbag Lft'   1.3  1  2  -51   43.0   41.79    6  1  2 3 4 5 6
  108  108  109  110 110 110
  2102  'LdCBtoAirbag Rgt'   1.3  1  2       -43.0   41.79    6  1  2 3 4 5 6
  108  108  109  110 110 110
!Airbag to Bolster connections
  2103  'LdAirbag-Blst Lft'  1.1  2 101       43.0   34.61    3  1  2  3  111
  111  112
  2104  'LdAirbag-Blst Rgt'  1.1  2 101 -51  -43.0   34.61    3  1  2  3  111
  111  112
!Change of area stiffness and shear
  2105  'LdCBtoLdBlst Lft'   1.1  1 101 -51   43.0   38.2     3  1  2  3 106
  106  107
  2106  'LdCBtoLdBlst Rgt'   1.1  1 101 -51  -43.0   38.2     3  1  2  3 106
  106  107
!lateral dynamic airbag connection (BMG 5/8/14)
  2107  'CB-LdBagLftDyn'       1  1  2        43.0   38.2     2   160
  2108  'LdBag-LdBlstLftDyn'   1  2 101 -51   43.0   38.2     2   161
  2109  'CB-LdBagRgtDyn'       1  1  2  -51  -43.0   38.2     2   160
  2110  'LdBag-LdBlstRgtDyn'   1  2 101 -51  -43.0   38.2     2   161
!Secondary Lateral Damper
  2111  'SLatDmpLd Lft  '  1  1 101  -57   43.0   38.2  2 162
  2112  'SLatDmpLd Rgt  '  1  1 101       -43.0   38.2  2 162
!Secondary Vertical Damper
  2113  'SVrtDmpLd Lft  '  1  1 101        43.0   38.2  3 163
  2114  'SVrtDmpLd Rgt  '  1  1 101  -45  -43.0   38.2  3 163
!Anti-Roll Bar
  2115  'Roll Bar Lead  '  1  1 102  -51   0      12.0  4 164
!
!Trail Truck
!Carbody to Airbag connections
!2point suspension
  2201  'TrCBtoAirbag Lft'   1.3  1   3         43.0   41.79   6  1  2 3 4 5
  6  108  108  109  110 110 110
  2202  'TrCBtoAirbag Rgt'   1.3  1   3  -765  -43.0   41.79   6  1  2 3 4 5
  6  108  108  109  110 110 110
!Airbag to Bolster connections
  2203  'TrAirbag-Blst Lft'  1.1  3  201 -765   43.0   34.61   3  1  2  3
  111  111  112
  2204  'TrAirbag-Blst Rgt'  1.1  3  201 -765  -43.0   34.61   3  1  2  3
  111  111  112
!Change of area stiffness and shear
  2205  'TrCBtoTrBlst Lft'   1.1  1  201 -765   43.0   38.2    3  1  2  3 106
  106  107
  2206  'TrCBtoTrBlst Rgt'   1.1  1  201       -43.0   38.2    3  1  2  3 106
       107
!lateral dynamic airbag connection (BMG 5/8/14)
  2207  'CB-TlBagLftDyn'       1  1  3          43.0   38.2     2   160
  2208  'TlBag-TlBlstLftDyn'   1  3 201 -765    43.0   38.2     2   161
  2209  'CB-TlBagRgtDyn'       1  1  3  -765  -43.0   38.2     2   160
```

```
  2210  'TlBag-TlBlstRgtDyn'   1  3 201 -765  -43.0   38.2      2   161
!Secondary Lateral Damper
  2211  'SLatDmpTr Lft  '  1   1 201   -759  43.022 38.2   2 1622
  2212  'SLatDmpTr Rgt  '  1   1 201   -759 -43.022 38.2   2 1622
!Secondary Vertical Damper
  2213  'SVrtDmpTr Lft  '  1   1 201   -771  43.022 38.2   3 1632
  2214  'SVrtDmpTr Rgt  '  1   1 201   -771 -43.022 38.2   3 1632
!Anti-Roll Bar22
  2215  'Roll Bar Trail '  1   1 202   -765  022     12.0   4 164
!
! ************************ A-Truck Connections ****************************
!
!  Secondary Carbody-Bolster Lateral Bumpstop, fore and aft
!::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::
:
 103  'ALdLatBS Fore  '  1      1 101  -35.6722 0.0  31.372   2        5
 104  'ALdLatBS Aft   '  1      1 101  -66.3322 0.0  31.372   2        5
!
!  Traction link between carbody and bolster (2 per truck)
!::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::
:
 109  'A Lt TractionRd'  1.1    1 101  -51.00  53.5  19.522 3 1 2 32    8  9  9
 110  'A Rt TractionRd'  1.1    1 101  -51.00 -53.5  19.522 3 1 2 32    8  9  9
!
!  Bolster to Truck Frame connections
!  Longitudinal and lateral connection, bolster to center pin on truck frame
!::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::
:
 111  'A Bol-Trk CBear'  1.1 101 102  -51.022  0.0  18.25   2 1 2     10 10
!
!  Longitudinal and lateral bolster - center plate for tipping and pitch (24"
centerplate)
!::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::
:
 112  'A Lft C.P.Conn.'  6.2 101 102  -51.0    12.0  18.25   3 122    11
 113      Rgt C.P.Conn.'  6.2 101 102  -51.0   -12.0  18.25   3 122    11
 114  'A Frt C.P.Conn.'  6.2 101 102  -39.022  0.0  18.25   3 2      11
 115  'A Trl C.P.Conn.'  6.2 101 102  -63.022  0.0  18.25   3 222    11
!
!  Side bearing connections - Bolster to Truck Frame
!::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::
:
 116  'A-end Gap SB Lt'  1.2 101 102  -51.022 40.72 25.502     3     12
 117  'A-end Gap SB Rt'  1.2 101 102  -51.0   -40.72 25.5022    3     12
!
!  Primary suspension - truck frame to equalizer beam connections
!2::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::22
:
 118  'A Ld Lt Fr-Eq   '  1.21 102 10322-22.022 39.5  18.18   2 12   3  13   14
 119  'A Ld Rt Fr-Eq   '  1.1 102 104   -22.022-39.52218.18  2 1    3  13   14
 120  'A Tr Lt Fr-Eq   '  1.1 102 103   -80.022 39.52218.18  2 1    3  13   14
 121  'A Tr Rt Fr-Eq   '  1.1 102 104   -80.022-39.52218.18  2 1    3  13   14
!
! Truck frame to axle connections
! No vertical load transferred between truck frame and axle boxes
! Truck Frame provides only rotation stops and guides for axle boxes
!2Connections are placed vertically at axle center22
!::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::22
:
 122  'A Frame Lft-Ax1'  1.1 102 105    0.0    39.5  18.0    3 1 2  6    15 16 17
 123  'A Frame Rgt-Ax1'  1.1 102 105    0.0   -39.5  18.022 3 1 2  62   15 16 17
 124  'A Frame Lft-Ax2'  1.1 102 106 -102.0    39.5  18.0    3 1 2  6    15 16 17
 125  'A Frame Rgt-Ax2'  1.1 102 106 -102.0   -39.5  18.022 3 1 2  62   15 16 17
!
```

```
!
:
 126  'A Frame Lft-Axl'  2.1   102 105    0.0   39.5  18.0         3
 18
 127  'A Frame Rgt-Axl'  2.1   102 105    0.0  -39.5  18.0::       3
 18
 128  'A Frame Lft-Ax2'  2.1   102 106 -102.0   39.5  18.0         3
 18
 129  'A Frame Rgt-Ax2'  2.1   102 106 -102.0  -39.5  18.0::       3
 18
!
! Equalizer beam to axle connections::
!:::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::
:
 130  'Ld Lft Equl Ax1'  1.1   103 105    0.0   39.5  18.0   3 1 2 3     19 20
 21
 131  'Ld Rgt Equl Ax1'  1.1   104 105    0.0  -39.5  18.0:: 3 1 2 3:    19 20
 21
 132  'Tr Lft Equl Ax2'  1.1   103 106 -102.0   39.5  18.0   4 1 2 3 4   19 20
 21 22
 133  'Tr Rgt Equl Ax2'  1.1   104 106 -102.0  -39.5  18.0:: 4 1 2 3 4:  19 20
 21 22
!  Wheel/rail connections
 134  'Axle 1 Left W/R':   4    105        0.0   29.75  0.0      1
 135  'Axle 1 Rght W/R'    4    105        0.0  -29.75: 0.0::    1
 136  'Axle 2 Left W/R'    4    106     -102.0:: 29.75: 0.0::    2
 137  'Axle 2 Rght W/R'    4    106     -102.0: -29.75: 0.0::    2
!
! ************************ B-Truck Connections:****************************:
!
!  Secondary Carbody-Bolster Lateral Bumpstop, fore and aft
!::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::
:
 203  'BLdLatBS Fore  '  1     1 201 -749.67   0.0  31.37::  2        5
 204  'BLdLatBS Aft   '  1     1 201 -780.33   0.0  31.37    2        5
!
!  Traction link between carbody and bolster (2 per truck)
!::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::
:
 209  'B Lt TractionRd'  1.1   1 201 -765.00  53.5  19.5   3 1 2 3    8  9  9
 210  'B Rt TractionRd'  1.1   1 201 -765.00 -53.5  19.5   3 1 2 3    8  9  9
!
!  Bolster to Truck Frame connections
!  Longitudinal and lateral connection, bolster to center pin on truck frame
!::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::
:
 211  'B Bol-Trk CBear'  1.1 201 202 -765.0    0.0  18.25  2 1 2::   10 10
!
!  Longitudinal and lateral bolster - center plate for tipping and pitch (24"
centerplate)
!::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::
:
 212  'B Lft C.P.Conn.'  6.2 201 202 -765.0   12.0  18.25  3 1      11
 213  'B Rgt C.P.Conn.'  6.2 201 202 -765.0  -12.0::18.25  3 1:     11
 214  'B Frt C.P.Conn.'  6.2 201 202 -753.0    0.0  18.25  3 2      11
 215  'B Trl C.P.Conn.'  6.2 201 202 -777.0    0.0  18.25  3 2      11
!
!  Side bearing connections - Bolster to Truck Frame
!::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::
:
 216  'B-end Gap SB Lt'  1.2 201 202 -765.0   40.72 25.50     3     12
 217  'B-end Gap SB Rt'  1.2 201 202 -765.0  -40.72 25.50::   3     12
!
```

```
!  Primary suspension - truck frame to equalizer beam connections
!:::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::
:
 218  'B Ld Lt Fr-Eq  '  1.1 202 203 -736.0   39.5  18.18  2 1   3  13   14
 219  'B Ld Rt Fr-Eq  '  1.1 202 204 -736.0  -39.5  18.18  2 1   3  13   14
 220  'B Tr Lt Fr-Eq  '  1.1 202 203 -794.0   39.5  18.18  2 1   3  13   14
 221  'B Tr Rt Fr-Eq  '  1.1 202 204 -794.0  -39.5  18.18  2 122 3  132  14
!
! Truck frame to axle connections
! No vertical load transferred between truck frame and axle boxes
! Truck Frame provides only rotation stops and guides for axle boxes
! Connections are placed vertically at axle center
!:::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::
:
 222  'B Frame Lft-Ax1'  1.1 202 205 -714.0   39.5  18.0   3 1 2  6      16
 223  'B Frame Rgt-Ax1'  1.1 202 205 -714.0  -39.5  18.022 3 1 22 6   15 16 17
 224  'B Frame Lft-Ax2'  1.1 202 206 -816.0   39.5  18.0   3 1 2  6   15 16 17
 225  'B Frame Rgt-Ax2'  1.1 202 206 -816.0  -39.5  18.022 3 1 2  62  15 16 17
!
!  Truck frame to axle gap and friction connections
!:::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::
:
 226  'B Frame Lft-Ax1'  2.1   202 205 -714.0   39.5  18.0         3
 18
 227  'B Frame Rgt-Ax1'2 2.1   202 205 -714.0  -39.5  18.022       3
 18
 228  'B Frame Lft-Ax2'  2.1   202 206 -816.0         18.0         3
 18
 229  'B Frame Rgt-Ax2'  2.1   202 206 -816.0  -39.5  18.022       3
 18
!
!2Equalizer beam to axle connections22
!:::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::22
:
 230  'Ld Lft Equl Ax3'  1.1   203 205 -714.0   39.5  18.0   3 1 2 3     19 20
 21
 231  'Ld Rgt Equl Ax3'  1.1   204 205 -714.0  -39.5  18.022 3 1 2 32    19 20
 21
 232  'Tr Lft Equl Ax4'  1.1   203 206 -816.0   39.5  18.0   4 1 2 3 4   19 20
 21 22
 233  'Tr Rgt Equl Ax4'  1.1   204 206 -816.0         18.022 4 1 2 3 4   19 20
 21 22
!  Wheel/rail connections
 234  'Axle 3 Left W/R'    4   205     -714.022 29.75  0.022   3
 235  'Axle 3 Rght W/R'    4   205     -714.0  -29.75  0.022   3
 236  'Axle 4 Left W/R'    4   206     -816.022 29.75  0.02    4
 237  'Axle 4 Rght W/R'    4   206     -816.0  -29.75  0.0     4
! Tow Rope to ground through car body C.G.22
 238  'Tow Rope - Grnd'   1   1   0 -408.00   0.0  64.17    1         1

\CHARACTERISTIC DATA
! Tow rope
    1    1    0      1.E9     -1.E922
! Secondary Lateral Bumpstop
    5    6    0      1.E9     -1.E922
! Traction rod longitudinal characteristics
    8    10   11      1.E9    -1.E9
! Traction rod lateral and vertical characteristics
    9    12   13      1.E9    -1.E9
! Center plate longitudinal/lateral pin connection
   10    14   15      1.E9    -1.E9
! Center plate friction (vertical)
   11    16   17     3.0      -3.0        0.E0    1.E622  1.E3    0.2
! Gap element for CC sidebearings 0.25" clearance
```

```
!
   13    20   21      1.E9     -1.E9
   14    22   23      1.E9     -1.E9
! Truck frame to axle - Longitudinal, lateral, and yaw characteristics
! Bearing adapter vertical plus friction longitudinal and lateral
! Stops for longitudinal and lateral 1/16 inches
   15    24   25      1.E9     -1.E9
   16    26   25      1.E9     -1.E9
! Soft yaw connection
   17    27   25      1.E9     -1.E9
! Truck frame-axle vertical friction and stops
   18    28  2.0   -6.0   1E6   1E6   1E3
! Equalizer beam to axle box - Longitudinal and lateral connections
   19    29   30      1.E9     -1.E9
   20    31   32      1.E9     -1.E9
! Vertical equalizer beam to axle
   21    33   34      0.0      -1.E9
! Equalizer beam to axle boxes roll and yaw stiffness
   22    35   0       1.E9     -1.E9
!Airbag shear static stiffness
  106   110    0   1.0e9      -1.0e9
!Airbag veritcal dAe/dz
  107   112    0   1.0e9      -1.0e9
!Dummy Lat & Long connection
  108   116   114   1.0e9      -1.0e9
!Airbag veritcal pedestal stiffness - Airbag vertical stiffness
  109   115    0   1.0e9      -1.0e9
!Dummy airbag roll (for roll moment due to shear)
  110  0    0    1.0e9      -1.0e9
!Long/Lat AB to Bolster
  111  155    156    1.0e9      -1.0e9
!Airbag vertical reservoir stiffness and orifice damping
  112  118    119    1.0e9      -1.0e9
!Dynamic long & lat airbag connection - Spring Damper in Series
  160  160    0    1.0e9      -1.0e9
  161  0      161  1.0e9      -1.0e9
!Secondary Lateral Damper
  162  0  162  1e9 -1e9
!Secondary Lateral Damper
  163  0  163  1e9 -1e9
!Anti-Roll Bar
  164 164  0   1e9 -1e9

\WHEEL/RAIL ELEMENT
     2.E5  5.0E2    2.E5   5.0E2
     1        18.0      .F.       0        0
     2        18.0      .F.       0        0
     3        18.0      .F.       0        0
     4        18.0      .F.       0        0

\PWL DATA
!
!  Tow rope to ground
!
  1    2     0.0       1.0E3
             0.0       1.0
! Secondary Lateral Bumpstop, 0.5" Gap (Firestone Dwg XN3-102-3)
  6    8    0.0    0.0  275.00  650.00  1200.00  2000.00  3250.00  6000.00
            0.0    0.5   0.75    1.00     1.25     1.50     1.75     2.00
! Traction Rod Connections
 10    2     0.0       1.E5
             0.0       1.0
 11    2     0.0       1.E3
```

```
            0.0        1.0
!  Traction rod lateral and vertical stiffness and damping
 12    2    0.0      200.0
            0.0        1.0
 13    2    0.0        2.0
            0.0        1.0
!
! ****************
!  Longitudinal0and lateral pin connections
         2    0.0      1.E600
              0.0      1.0
 15      2    0.0      1.E300
              0.0      1.000
!  Center plate vertical
!  Static 124,296.5 / 8 = 15,537.06
 16    4    -1.15537E500  -1.5537E400 0.00         0.0
            -0.0100        0.000      0.0015537    1.0
 17    2     0.000         5.E300
             0.000         1.000
!00Gap element characteristics00
!
 18    2     0.0       1.E600
             0.0       1.0
       2     0.0       1.E3
             0.0       1.0
! ******************* Primary Suspension0****************
!
!  Truck frame to equalizer beam - Longitudinal connections
!  (9,350 lb/in per coil)
 20    2     0.0   9350.0
             0.0      1.0
 21    2     0.0      1.0
             0.0      1.0
!  Truck frame to equalizer beam - Vertical connections
! w/ static offset  (10,250 lb/in per coil)
!2200  2    -1.5664E40  0.0
!            0.000      1.52800
 2200  2    -16212.800  0.000
             0.000      1.5817400
 230   2     0.000    1.0
             0.000    1.0
! *********** Truck Frame to Axle Box Connections0*********
!
!  Longitudinal connections 1/16 inch clearance
!
 24    3     0.0       1.0E3    1.E6
             0.0       0.0625   1.0
!  Damping for longitudinal, lateral and yaw truck frame to axle connections
!
 25    2     0.0      1.E300
             0.0      1.000
! Used characteristic from HEP2 but with primary shear of GSI design
! 0.08375" of travel with 90% of primary spring shear stiffness
! 0.01" of travel with 10kip/in stiffness (rubber damper?)
 26    4     0.0     704.76     804.76     10.008E5
             0.0       0.08375    0.09375  1.09375
!  Truck frame to axle - Yaw connections from HEP2
!
       3     0.0       1.0E4    6.4E7
             0.0       0.039    1.039
!  Truck frame-axle box friction
 28    2   250.0     250.0
           -10.0      10.0
! *********  Equalizer Beam and Truck Frame to Axle Box Connections0*******
```

```
!
!  Longitudinal connections
!
 29    2     0.0       1.E6
             0.0       1.0
 30    2     0.0       1.E3
             0.0       1.0
!
!  Lateral connections
!
 31    2     0.0       1.E6
             0.0       1.0
 32    2     0.0       1.E3
             0.0       1.0
!
! Vertical connections
! Static load on axle boxes (4/truck):  142,530.4 / 8 = 17,816.3 lb/in
!
 33    4    -1.7816E5   -1.7816E4    0.0        0.0
            -0.1         0.0         0.017816   1.0
 34    2     0.0       1.E3
             0.0       1.0
!
!  General yaw stiffness - assumed
!
       2     0.0       6.4E7
             0.0       1.0
!
! Lat/Long Change of area stiffness
  110      2     0.0    425.0
                 0.0     1.0
!Airbag vertical dAe/dz
  112     2   0.0    200.0
            0.0      1.0
!Airbag dummy long and lat
  114     2   0.0      0.0
            0.0      1.0
!Airbag vertical pedestal stiffness
  115    2   -27390   0.0
             0.0      4.957172001
!Long/Lat dynamic shear stiffness - no stiffness
  116    2   0.0       0.0
           0.0      1.0
!Airbag vertical reservoir stiffness
  118    2   -27390  0.0
           0.0      4.82841487
!Orifice damping assuming a 15mm diameter
  119  12   0   27.38345148     109.5338059     246.4510633     438.1352237
       985.8042534     1752.540895     2738.345148     5367.156491
       10953.38059     24645.10633     43813.52237
           0   0.196850394     0.393700787     0.590551181     0.787401575
       1.181102362     1.57480315      1.968503937     2.755905512
       3.937007874     5.905511811     7.874015748
! Very stiff connection of airbag to bolster. long and lat
  155   2   0.0   1e6
            0.0   1.0
  156   2   0.0   1e3
            0.0   1.0
!Long & lat dynamic airbag connection
  160   2   0.0  2500.0
            0.0   1.0
  161   2   0.0  500.0
            0.0   1.0
!Secondary Lateral Damper
```

```
  162   2   0.0  50
            0.0   1.0
!Secondary Vertical Damper
  163   2   0.0  25
            0.0   1.0
!Anti-Roll Bar
  164   2   0.0
            0.0   1.0
```

System file (.SYS) for NUCARS Version 2005
===

\SYSTEM TITLE
Equalizer beam truck, Single-level car, 4-point air spring secondary suspension

Description	Wt/item (lb)	Wt/Truck (lb)
Carbody	63000	63000
Truck frame	7007	7007
Truck bolster	3204	3204
Equalizer beam	1055	2110
Axle Assembly	4290	8580

\BODY DATA

```
! ** Car body **
  1   'Car Body            '        -408.00      0.0       64.17
       6  1 2 3 4 5 6                163.17      4.2159E5  1.4352E7  1.4363E7
        'AirBag Ld '                 -51.0       0.0       38.2
       5   1 2 3 4 6                   0.3626    1.70e2    0.0       1.70e2
        'AirBag Trl'                -765.0       0.0       38.2
      5   1 2      6                   0.3626    1.70e2    0.0       1.70e2
!
! ** Truck A **
!
 101   'Bolster A          '         -51.0       0.0       23.9
       6    1 2 3 4 5 6                8.299     7.4E03   659.6       7.6E03
 102   'Truck Frame A      '         -51.0       0.0       28.7
       6    1 2 3 4 5 6               18.148     2.72E04   3.79E04    5.53E04
 103   'Eqlizer A Left     '         -51.0      39.5       14.2
       6    1 2 3 4 5 6                2.73    145.0       23.45E02  22.03E02
 104   'Eqlizer A Right    '         -51.0     -39.5       14.2
       6    1 2 3 4 5 6                2.73    145.0       23.45E02  22.03E02
 105   'Axle Number 1      '           0.0       0.0       18.0
       5    1 2 3 4   6               11.111    10.9E03    12.01E02  10.9E03
 106   'Axle Number 2      '        -102.0       0.0       18.0
       5    1 2 3 4   6               11.111    10.9E03    12.01E02  10.9E03
! ** Truck B **
 201   'Bolster B          '        -765.0       0.0       23.9
       6    1 2 3 4 5 6                8.299     7.4E03   659.6       7.6E03
 202   'Truck Frame B      '        -765.0       0.0       28.7
       6    1 2 3 4 5 6               18.148     2.72E04   3.79E04    5.53E04
 203   'Eqlizer B Left     '        -765.0      39.5       14.2
       6    1 2 3 4 5 6                2.73    145.0       23.45E02  22.03E02
 204   'Eqlizer B Right    '        -765.0     -39.5       14.2
       6    1 2 3 4 5 6                2.73    145.0       23.45E02  22.03E02
 205   'Axle Number 3      '        -714.0       0.0       18.0
       5    1 2 3 4   6               11.111    10.9E03    12.01E02  10.9E03
 206   'Axle Number 4      '        -816.0       0.0       18.0
       5    1 2 3 4   6               11.111    10.9E03    12.01E02  10.9E03
```

Give the number of connections, then for each, identify a name in single quotes up to 20 characters, a position relative to the chosen datum, numbers for the bodies at each end, 0 for an earth in local track coords., a number indicating the degree of freedom, translational 1,2,3 or rotational 4,5,6, in x,y,z resp., including 2 for lateral wheel motion, and the type:

1 - parallel pair of spring and damper characteristics
2 - series pair of spring and damper characteristics

3 - device with hysteresis between 2 PWL characteristics, e.g. carriage spring or load sensitive suspension
4 - lateral/longitudinal suspension of the wheel on rail
5 - connection force as a history of the distance moved

and the identification number for each of type 1, 2 and 3, the axle number for type 4, input function number for type 5.

Note - single characteristics are treated as parallel pairs with the missing characteristic set to zero in the subsequent table.

```
 Conn # ' 15 CHARACTER  ' Type Body 1 & 2  Posn in X, Y, & Z   DoF No.
---------------------------------------------------------------------------
\CONNECTION DATA

!
!Lead Truck
!Carbody to Airbag connections
!2point suspension
  2101  'LdCBtoAirbag Lft'   1.3  1  2  -51   43.0   41.79    6  1  2 3 4 5 6
  108  108  109  110 110 110
  2102  'LdCBtoAirbag Rgt'   1.3  1  2  -51  -43.0   41.79    6  1  2 3 4 5 6
  108  108  109  110 110 110
!Airbag to Bolster connections
  2103  'LdAirbag-Blst Lft'  1.1  2 101 -51   43.0   34.61    3  1  2  3  111
  111  112
  2104  'LdAirbag-Blst Rgt'  1.1  2 101 -51  -43.0   34.61    3  1  2  3  111
  111  112
!Change of area stiffness and shear
  2105  'LdCBtoLdBlst Lft'   1.1  1 101 -51   43.0   38.2     3  1  2  3 106
  106  107
  2106  'LdCBtoLdBlst Rgt'   1.1  1 101 -51  -43.0   38.2     3  1  2  3 106
  106  107
!lateral dynamic airbag connection (BMG 5/8/14)
  2107  'CB-LdBagLftDyn'       1  1  2  -51   43.0   38.2     2   160
  2108  'LdBag-LdBlstLftDyn'   1  2 101 -51   43.0   38.2     2   161
  2109  'CB-LdBagRgtDyn'       1  1  2  -51  -43.0   38.2     2   160
  2110  'LdBag-LdBlstRgtDyn'   1  2 101 -51  -43.0   38.2     2   161
!Secondary Lateral Damper
  2111  'SLatDmpLd Lft  '  1   1 101  -57   43.0   38.2  2 162
  2112  'SLatDmpLd Rgt  '  1   1 101  -57  -43.0   38.2  2 162
!Secondary Vertical Damper
  2113  'SVrtDmpLd Lft  '  1   1 101  -45   43.0   38.2  3 163
  2114  'SVrtDmpLd Rgt  '  1   1 101  -45  -43.0   38.2  3 163
!Anti-Roll Bar
  2115  'Roll Bar Lead  '  1   1 102  -51   0      12.0  4 164
!
!Trail Truck
!Carbody to Airbag connections
!2point suspension
  2201  'TrCBtoAirbag Lft'   1.3  1   3  -765   43.0   41.79   6  1  2 3 4 5
  6  108  108  109  110 110 110
  2202  'TrCBtoAirbag Rgt'   1.3  1   3  -765  -43.0   41.79   6  1  2 3 4 5
  6  108  108  109  110 110 110
!Airbag to Bolster connections
  2203  'TrAirbag-Blst Lft'  1.1  3  201 -765   43.0   34.61   3  1  2  3
  111  111  112
  2204  'TrAirbag-Blst Rgt'  1.1  3  201 -765  -43.0   34.61   3  1  2  3
  111  111  112
!Change of area stiffness and shear
  2205  'TrCBtoTrBlst Lft'   1.1  1  201 -765   43.0   38.2    3  1  2  3 106
  106  107
  2206  'TrCBtoTrBlst Rgt'   1.1  1  201 -765  -43.0   38.2    3  1  2  3 106
  106  107
!lateral dynamic airbag connection
```

```
  2207  'CB-TlBagLftDyn'       1  1  3  -765:: 43.0:  38.2      2   160
  2208  'TlBag-TlBlstLftDyn'   1  3 201 -765   43.0   38.2      2   161
  2209  'CB-TlBagRgtDyn'       1  1  3  -765  -43.0:: 38.2      2   160
  2210  'TlBag-TlBlstRgtDyn'   1  3 201 -765  -43.0:: 38.2      2   161
!Secondary Lateral Damper
  2211  'SLatDmpTr Lft  '  1   1 201        43.0:: 38.2  2 162
  2212  'SLatDmpTr Rgt  '  1   1 201  -759 -43.0:: 38.2  2 162:
!Secondary Vertical Damper
  2213  'SVrtDmpTr Lft  '  1   1 201  -771  43.0:: 38.2  3 163:
  2214  'SVrtDmpTr Rgt  '  1   1 201  -771 -43.0:: 38.2  3 163:
!Anti-Roll Bar::
  2215  'Roll Bar Trail '  1   1 202  -765  0::    12.0  4 164
!
! ************************ A-Truck Connections:***************************
!
!  Secondary Carbody-Bolster Lateral Bumpstop, fore and aft
!::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::
:
 103  'ALdLatBS Fore  '  1     1 101  -35.67:: 0.0  31.37:   2        5
 104  'ALdLatBS Aft   '  1     1 101  -66.33:: 0.0  31.37::  2        5
!
!::Traction link between carbody and bolster (2 per truck)
!::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::
:
 109  'A Lt TractionRd'  1.1   1 101  -51.00  53.5  19.5:: 3 1 2 3:   8  9  9
 110  'A Rt TractionRd'  1.1   1 101  -51.00 -53.5  19.5:: 3 1 2 3:   8  9  9
!
!  Bolster to Truck Frame connections
!  Longitudinal and lateral connection, bolster to center pin on truck frame
!::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::
:
 111  'A Bol-Trk CBear'  1.1 101 102  -51.0::  0.0  18.25  2 1 2     10 10
!
!  Longitudinal and lateral bolster - center plate for tipping and pitch (24"::
centerplate)
!::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::
:
 112  'A Lft C.P.Conn.'  6.2 101 102  -51.0:: 12.0  18.25  3 1:     11
 113  'A Rgt C.P.Conn.'  6.2 101 102  -51.0  -12.0  18.25  3 1::    11
 114  'A Frt C.P.Conn.'  6.2 101 102  -39.0::  0.0  18.25  3 2      11
 115  'A Trl C.P.Conn.'  6.2 101 102  -63.0::  0.0  18.25  3 2      11
!
!  Side bearing connections - Bolster to Truck Frame
!::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::
:
 116  'A-end Gap SB Lt'  1.2 101 102  -51.0:: 40.72 25.50:    3     12
 117  'A-end Gap SB Rt'  1.2 101 102  -51.0  -40.72 25.50::   3     12
!
!  Primary suspension - truck frame to equalizer beam connections
!::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::
:
 118  'A Ld Lt Fr-Eq  '  1.1 102 103::-22.0:: 39.5  18.18  2 1   3  13   14
 119  'A Ld Rt Fr-Eq  '  1.1 102 104::-22.0::-39.5::18.18  2 1   3  13   14
 120  'A Tr Lt Fr-Eq  '  1.1 102 103::-80.0:: 39.5::18.18  2 1   3  13   14
 121  'A Tr Rt Fr-Eq  '  1.1 102 104::-80.0::-39.5::18.18  2 1   3  13   14
!
! Truck frame to axle connections
! No vertical load transferred between truck frame and axle boxes
! Truck Frame provides only rotation stops and guides for axle boxes
! Connections are placed vertically at axle center
!::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::
:
 122  'A Frame Lft-Axl'  1.1 102 105    0.0   39.5  18.0   3 1 2  6   15 16 17
 123  'A Frame Rgt-Axl'  1.1 102 105    0.0  -39.5  18.0   3 1 2  6   15 16 17
```

```
 124  'A Frame Lft-Ax2'  1.1 102 106 -102.0   39.5  18.0   3 1 2  6   15 16 17
 125  'A Frame Rgt-Ax2'  1.1 102 106 -102.0  -39.5  18.0   3 1 2  6   15 16 17
!
!00 Truck frame to axle gap and friction connections00
!::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::
:
 126  'A Frame Lft-Ax1'  2.1   102 105    0.0   39.5  18.0          3
 18
 127  'A Frame Rgt-Ax1'  2.1   102 105    0.0  -39.5  18.000       3
 18
 128  'A Frame Lft-Ax2'  2.1   102 106 -102.0   39.5  18.0          3
 18
 129  'A Frame Rgt-Ax2'  2.1   102 106 -102.0  -39.5  18.000       3
 18
!
! Equalizer beam to axle connections00
!::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::00
:
 130  'Ld Lft Equl Ax1'  1.1   103 105    0.0   39.5  18.0   3 1 2 3     19 20
 21
 131  'Ld Rgt Equl Ax1'  1.1   104 105    0.0  -39.5  18.000 3 1 2 30    19 20
 21
 132  'Tr Lft Equl Ax2'  1.1   103 106 -102.0         18.0   4 1 2 3 4   19 20
 21 22
 133  'Tr Rgt Equl Ax2'  1.1   104 106 -102.0  -39.5  18.000 4 1 2 3 40  19 20
 21 22
!  Wheel/rail connections
 134  'Axle 1 Left W/R'    4   105         0.0   29.75  0.000   1
      'Axle 1 Rght W/R'    4   105         0.0  -29.75  0.000   1
      'Axle 2 Left W/R'0   4   106      -102.000 29.75  0.000   20
 137  'Axle 2 Rght W/R'0   4   106      -102.0  -29.75  0.000   2
!
! ************************ B-Truck Connections ****************************
!
!  Secondary Carbody-Bolster Lateral Bumpstop, fore and aft
!::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::
:
 203  'BLdLatBS Fore  '  1     1 201 -749.67   0.0  31.37    2        5
 204  'BLdLatBS Aft   '  1     1 201 -780.33   0.0  31.37    2        5
!
!  Traction link between carbody and bolster (2 per truck)
!::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::
:
 209  'B Lt TractionRd'  1.1   1 201 -765.00  53.5  19.5   3 1 2 3    8  9  9
 210  'B Rt TractionRd'  1.1   1 201 -765.00 -53.5  19.5   3 1 2 3    8  9  9
!
!  Bolster to Truck Frame connections
!  Longitudinal and lateral connection, bolster to center pin on truck frame
!::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::
:
 211  'B Bol-Trk CBear'  1.1 201 202 -765.0    0.0  18.25  2 1 2     10 10
!
!  Longitudinal and lateral bolster - center plate for tipping and pitch (24"
centerplate)
!::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::
:
 212  'B Lft C.P.Conn.'  6.2 201 202 -765.0   12.0  18.25  3 1       11
 213  'B Rgt C.P.Conn.'  6.2 201 202 -765.0  -12.00018.25  3 10      11
 214  'B Frt C.P.Conn.'  6.2 201 202 -753.0    0.0  18.25  3 2       11
 215  'B Trl C.P.Conn.'  6.2 201 202 -777.0    0.0  18.25  3 2       11
!
!  Side bearing connections - Bolster to Truck Frame
!::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::
:
```

```
 216  'B-end Gap SB Lt'  1.2 201 202 -765.0   40.72 25.50     3     12
 217  'B-end Gap SB Rt'  1.2 201 202 -765.0  -40.72 25.5022   3     12
!
!  Primary suspension - truck frame to equalizer beam connections
!::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::
:
 218  'B Ld Lt Fr-Eq  '  1.1 202 203 -736.0   39.5  18.18  2 1   3  13   14
 219  'B Ld Rt Fr-Eq  '  1.1 202 204 -736.0  -39.52218.18  2 12  3  13   14
 220  'B Tr Lt Fr-Eq  '  1.1 202 203 -794.0   39.52218.18  2 1   3  13   14
 221  'B Tr Rt Fr-Eq  '  1.1 202 204 -794.0  -39.52218.18  2 12  3  13   14
!
! Truck frame to axle connections
! No vertical load transferred between truck frame and axle boxes
! Truck Frame provides only rotation stops and guides for axle boxes
! Connections are placed vertically at axle center
!::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::
:
 222  'B Frame Lft-Ax1'  1.1 202 205 -714.0   39.5  18.0   3 1 2  6   15 16 17
 223  'B Frame Rgt-Ax1'  1.1 202 205 -714.0  -39.5  18.022 3 1 2  62  15 16 17
 224  'B Frame Lft-Ax2'  1.1 202 206 -816.0         18.0   3 1 2  6   15 16 17
 225  'B Frame Rgt-Ax2'  1.1 202 206 -816.0         18.022 3 1 2  6   15 16 17
!
!  Truck frame to axle gap and friction connections
!::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::
:
 226  'B Frame Lft-Ax1'  2.1   202 205 -714.0   39.5  18.0         3
 18
 227  'B Frame Rgt-Ax1'  2.1   202 205 -714.0  -39.5  18.022       3
 18
 228  'B Frame Lft-Ax2'  2.1   202 206 -816.0         18.0         3
 18
 229  'B Frame Rgt-Ax2'  2.1   202 206 -816.0         18.022       3
 18
!
! Equalizer beam to axle connections22
!::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::
:
 230  'Ld Lft Equl Ax3'  1.1   203 205 -714.0   39.5  18.0   3 1 2 3     19 20
 21
 231  'Ld Rgt Equl Ax3'  1.1   204 205 -714.0  -39.5  18.022 3 1 2 32    19 20
 21
 232  'Tr Lft Equl Ax4'  1.1   203 206 -816.0         18.0   4 1 2 3 4   19 20
 21 22
 233  'Tr Rgt Equl Ax4'  1.1   204 206 -816.0  -39.5  18.022 4 1 2 3 42  19 20
 21 22
!  Wheel/rail connections
 234  'Axle 3 Left W/R'    4   205      -714.022 29.75  0.02    3
 235  'Axle 3 Rght W/R'    4   205      -714.0  -29.75  0.022   3
 236  'Axle 4 Left W/R'    4   206      -816.022 29.75  0.02    4
 237  'Axle 4 Rght W/R'    4   206      -816.0  -29.75  0.022   4
! Tow Rope to ground through car body C.G.22
 238  'Tow Rope - Grnd'22 12  1   0 -408.00   0.0  64.17    1         1

\CHARACTERISTIC DATA
! Tow rope
    1    1    0      1.E9    -1.E9
! Secondary Lateral Bumpstop
    5    6    0      1.E9    -1.E9
! Traction rod longitudinal characteristics
    8    10   11      1.E9    -1.E9
! Traction rod lateral and vertical characteristics
    9    12   13      1.E9    -1.E9
! Center plate longitudinal/lateral pin connection
   10    14   15      1.E9    -1.E9
```

```
!
!
   12    18   19    1000.0      -0.25
! Primary suspension - truck frame - equalizer beam spring coils
   13    20   21      1.E9     -1.E9
   14    22   23      1.E9     -1.E9
! Truck frame to axle - Longitudinal, lateral, and yaw characteristics
! Bearing adapter vertical plus friction longitudinal and lateral
! Stops for longitudinal and lateral 1/16 inches
   15    24   25      1.E9     -1.E9
   16    26   25      1.E9     -1.E9
! Soft yaw connection
   17    27   25      1.E9     -1.E9
! Truck frame-axle vertical friction and stops
   18    28  2.0   -6.0   1E6   1E6   1E3
! Equalizer beam to axle box - Longitudinal and lateral connections
   19    29   30      1.E9     -1.E9
   20    31   32      1.E9     -1.E9
! Vertical equalizer beam to axle
   21    33   34      0.0      -1.E9
! Equalizer beam to axle boxes roll and yaw stiffness
   22    35    0      1.E9     -1.E9
!Airbag shear static stiffness
  106   110    0   1.0e9      -1.0e9
!Airbag veritcal dAe/dz
  107   112    0   1.0e9      -1.0e9
!Dummy Lat & Long connection
  108   116   114   1.0e9      -1.0e9
!Airbag veritcal pedestal stiffness - Airbag vertical stiffness
  109   115    0   1.0e9      -1.0e9
!Dummy airbag roll (for roll moment due to shear)
  110  0    0    1.0e9      -1.0e9
!Long/Lat AB to Bolster
  111  155   156    1.0e9      -1.0e9
!Airbag vertical reservoir stiffness and orifice damping
  112  118   119    1.0e9      -1.0e9
!Dynamic long & lat airbag connection - Spring Damper in Series
  160  160    0    1.0e9      -1.0e9
  161  0      161  1.0e9      -1.0e9
!Secondary Lateral Damper
  162  0  162  1e9 -1e9
!Secondary Lateral Damper
  163  0  163  1e9 -1e9
!Anti-Roll Bar
  164 164  0   1e9 -1e9

\WHEEL/RAIL ELEMENT
     2.E5  5.0E2    2.E5   5.0E2
     1        18.0      .F.       0        0
     2        18.0      .F.       0        0
     3        18.0      .F.       0        0
     4        18.0      .F.       0        0

\PWL DATA
!
!  Tow rope to ground
!
  1    2     0.0       1.0E3
             0.0       1.0
! Secondary Lateral Bumpstop, 0.5" Gap (Firestone Dwg XN3-102-3)
  6    8    0.0    0.0  275.00  650.00  1200.00  2000.00  3250.00  6000.00
            0.0    0.5    0.75    1.00     1.25     1.50     1.75     2.00
! Traction Rod Connections
```

```
 10    2     0.0       1.E5
             0.0       1.0
 11    2     0.0       1.E3
             0.0       1.0
!  Traction rod lateral and vertical stiffness and damping
 12    2     0.0     200.0
             0.0       1.0
 13    2     0.0       2.0
             0.0       1.0
!
! ****************
!  Longitudinal and lateral pin connections
           2    0.0      1.E6
                0.0      1.0
 15        2    0.0      1.E3
                0.0      1.0
!  Center plate vertical
!  Static 124,296.5 / 8 = 15,537.06
 16    4    -1.15537E5    -1.5537E4   0.0           0.0
            -0.01          0.0        0.0015537     1.0
 17    2     0.0           5.E3
             0.0           1.0
! Gap element characteristics
!
 18    2     0.0       1.E6
             0.0       1.0
 19    2     0.0       1.E3
             0.0       1.0
! ********************
!
!  Truck frame to equalizer beam - Longitudinal connections
!  (9,350 lb/in per coil)
 20    2     0.0   9350.0
             0.0      1.0
 21    2     0.0      1.0
             0.0      1.0
!  Truck frame to equalizer beam - Vertical connections
! w/ static offset  (10,250 lb/in per coil)
!22    2    -1.5664E4   0.0
!            0.0        1.528
 22    2    -10462.5    0.0
             0.0        1.02073
 23    2     0.0      1.0
             0.0      1.0
! *********** Truck Frame to Axle Box Connections *********
!
!  Longitudinal connections 1/16 inch clearance
!
 24    3     0.0       1.0E3    1.E6
             0.0       0.0625   1.0
!  Damping for longitudinal, lateral and yaw truck frame to axle connections
!
 25    2     0.0       1.E3
             0.0       1.0
! Used characteristic from HEP2 but with primary shear of GSI design
! 0.08375" of travel with 90% of primary spring shear stiffness
! 0.01" of travel with 10kip/in stiffness (rubber damper?)
 26    4     0.0     704.76     804.76     10.008E5
             0.0       0.08375    0.09375  1.09375
!  Truck frame to axle - Yaw connections from HEP2
!
 27    3     0.0       1.0E4    6.4E7
             0.0       0.039    1.039
!  Truck frame-axle box friction
```

```
         -2 -22 -22
 28    2   250.0    250.0
           -10.022   10.0
! *********  Equalizer Beam and Truck Frame to Axle Box Connections2*******
!
!  Longitudinal connections
!
 29    2     0.0       1.E6
             0.0       1.0
 30    2     0.0       1.E3
             0.0       1.0
!
!  Lateral connections
!
 31    2     0.0       1.E622
             0.0       1.022
 32    2     0.0       1.E322
             0.0       1.022
!
! Vertical connections
! Static load on axle boxes (4/truck):  142,530.4 / 8 = 17,816.3 lb/in
!
 33    4    -1.7816E522 -1.7816E422  0.0        0.0
            -0.122       0.0         0.017816   1.0
       2     0.022     1.E322
             0.022     1.022
!
!  General yaw stiffness - assumed
!
 35    2     0.0       6.4E7
             0.0       1.0
!
! Lat/Long Change of area stiffness
  110      2     0.0    425.0
                 0.0      1.0
!Airbag vertical dAe/dz
  112     2    0.0    200.0
             0.0      1.0
!Airbag dummy long and lat22
  114     2    0.0      0.0
             0.0      1.0
!Airbag vertical pedestal stiffness22
  115    2    -1614022 0.02
             0.0      4.472437977
!Long/Lat dynamic shear stiffness - no stiffness22
  116    2   0.0      0.0
            0.0      1.0
!Airbag vertical reservoir stiffness f22
  118     2   -16140  0.022
             0.0      4.356275304
!Orifice damping assuming a 15mm diameter22
  119  12   0   17.88501852     71.54007409     160.9651667     286.1602964
        643.8606668     1144.641185     1788.501852     3505.46363
        7154.007409     16096.51667     28616.02964
            0   0.196850394     0.393700787     0.590551181     0.787401575
        1.181102362     1.57480315      1.968503937     2.755905512
        3.937007874     5.905511811     7.874015748
! Very stiff connection of airbag to bolster. long and lat
  155   2   0.0   1e6
            0.0   1.0
  156   2   0.0   1e3
            0.0   1.022
!Long & lat dynamic airbag connection22
  160   2   0.0   1000
            0.0   1.0
```

```
              0.0   1.0
!Secondary Vertical Damper
  163   2   0.0   25
              0.0   1.0
!Anti-Roll Bar
  164   2   0.0
              0.0   1.0
```

```
System file (.SYS) for NUCARS Version 2015
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\SYSTEM TITLE
    Journal Spring, Bi-level car w/ 4-point secodary air spring suspension


\BODY DATA

! ** Car body
       'Car Body      '          -408.00       0.0       87
         6  1 2 3 4 5 6           282.32       1.1024E6  2.5206E7  2.4851E7
   2    'AirBag Ld '              -51.0        0.0      37.1
         5   1 2 3 4 6             0.3626     1.70e2   0.0      1.70e2
   3    'AirBag Trl'             -765.0        0.0      37.1
        5   1 2 3 4 6              0.3626     1.70e2   0.0      1.70e2
!
   4   ' Lead Bolster  '        -51.0000    0.0000     29.0
    5  1 2 3 4   6                   2.57   3823   122   3869
   5   ' Trail Bolster '      -765.0000    0.0000     29.0
    5  1 2 3 4   6                   2.57   3823   122   3869
   6   ' Lead Truck    '        -51.0000    0.0000     22.05
    6  1 2 3 4 5 6                   6.57   12009  9783  21268
   7   ' Trail Truck   '      -765.0000    0.0000     22.05
    6  1 2 3 4 5 6                   6.57   12009  9783  21268
   8   ' Axle Number 1 '          0.0000    0.0000     18.0000
    5  1 2 3 4   6                  12.0800   1.0810E+04  2.7600E+03
    1.0810E+04
   9   ' Axle Number 2 '      -102.0000    0.0000     18.0000
    5  1 2 3 4   6                  12.0800   1.0810E+04  2.7600E+03
    1.0810E+04
  10   ' Axle Number 3 '      -714.0000    0.0000     18.0000
    5  1 2 3 4   6                  12.0800   1.0810E+04  2.7600E+03
    1.0810E+04
  11   ' Axle Number 4 '      -816.0000    0.0000     18.0000
    5  1 2 3 4   6                  12.0800   1.0810E+04  2.7600E+03
    1.0810E+04


\CONNECTION DATA
  73
! 4-point airbag secondary suspension
!Lead Truck
!Carbody to Airbag connections
!2point suspension
  2101  'LdCBtoAirbag Lft'   1.3  1  2  -51   39.5   40.69     6  1  2 3 4 5 6
  108  108  109  110 110 110
  2102  'LdCBtoAirbag Rgt'   1.3  1  2  -51  -39.5   40.69     6  1  2 3 4 5 6
  108  108  109  110 110 110
!Airbag to Bolster connections
  2103  'LdAirbag-Blst Lft'  1.1  2  4  -51   39.5   33.51     3  1  2  3  111
  111  112
  2104  'LdAirbag-Blst Rgt'  1.1  2  4  -51  -39.5   33.51     3  1  2  3  111
  111  112
!Change of area stiffness and shear
  2105  'LdCBtoLdBlst Lft'   1.1  1  4  -51   39.5   37.1      3  1  2  3 106
  106  107
  2106  'LdCBtoLdBlst Rgt'   1.1  1  4  -51  -39.5   37.1      3  1  2  3 106
  106  107
!lateral dynamic airbag connection
  2107  'CB-LdBagLftDyn'      1  1  2  -51   39.5   37.1      2   160
  2108  'LdBag-LdBlstLftDyn'  1  2  4  -51          37.1      2   161
  2109  'CB-LdBagRgtDyn'      1  1  2  -51  -39.5   37.1      2   160
  2110  'LdBag-LdBlstRgtDyn'  1  2  4  -51  -39.5   37.1      2   161
```

```
!Secondary Lateral Damper
  2111  'SLatDmpLd Lft  '  1  1  4   -57   39.5   37.1  2 162
  2112  'SLatDmpLd Rgt  '  1  1  4   -57  -39.5   37.1  2 162
!Secondary Vertical Damper
  2113  'SVrtDmpLd Lft  '  1  1  4   -45   39.5   37.1  3 163
  2114  'SVrtDmpLd Rgt  '  1  1  4   -45  -39.5   37.1  3 163
!Anti-Roll Bar
  2115  'Roll Bar Lead  '  1  1  6   -51   0      12.0  4 164
!
!Trail Truck
!Carbody to Airbag connections
!2point suspension
  2201  'TrCBtoAirbag Lft'   1.3  1   3  -765   39.5   40.69    6  1  2 3 4 5
  6  108  108  109  110 110 110
  2202  'TrCBtoAirbag Rgt'   1.3  1   3  -765          40.69    6  1  2 3 4 5
  6  108  108  109  110 110 110
!Airbag to Bolster connections
  2203  'TrAirbag-Blst Lft'  1.1  3   5                33.51    3  1  2  3
  111  111  112
  2204  'TrAirbag-Blst Rgt'  1.1  3   5  -765          33.51    3  1  2  3
  111  111  112
!Change of area stiffness and shear
  2205  'TrCBtoTrBlst Lft'   1.1  1   5  -765          37.1     3  1  2  3 106
  106  107
  2206  'TrCBtoTrBlst Rgt'   1.1  1   5  -765          37.1     3  1  2  3 106
  106  107
!lateral dynamic airbag connection
  2207  'CB-TlBagLftDyn'       1  1  3  -765   39.5   37.1       2   160
  2208  'TlBag-TlBlstLftDyn'   1  3  5  -765   39.5   37.1       2   161
  2209  'CB-TlBagRgtDyn'       1  1  3  -765  -39.5   37.1       2   160
  2210  'TlBag-TlBlstRgtDyn'   1  3  5  -765          37.1       2   161
!Secondary Lateral Damper
  2211  'SLatDmpTr Lft  '  1  1  5   -759          37.1  2 162
  2212  'SLatDmpTr Rgt  '  1  1  5   -759 -39.5   37.1  2 162
!Secondary Vertical Damper
  2213  'SVrtDmpTr Lft  '  1  1  5         39.5   37.1  3 163
  2214  'SVrtDmpTr Rgt  '  1  1  5   -771 -39.5   37.1  3 163
!Anti-Roll Trail
  2215  'Roll Bar Trail '  1  1  7   -765  0      12.0  4 164
!
! Traction rods
      'Trctn Rd Ld Lft'  1.1   1   4    -51.0000   53.5000   19.6900   3 1 2 3
  12 13 13
  18  'Trctn Rd Ld Rgt'  1.1   1   4    -51.0000  -53.5000   19.6900   3 1 2 3
  12 13 13
  19  'Trctn Rd Tr Lft'  1.1   1   5   -765.0000   53.5000   19.6900   3 1 2 3
  12 13 13
  20  'Trctn Rd Tr Rgt'  1.1   1   5   -765.0000  -53.5000   19.6900   3 1 2 3
  12 13 13
!
! Bolster-truck frame centerplate stiff connections
  21  'Ld Blstr-Ld Trk'  1.1   4   6    -51.0000    0.0000   21.3500   2 1 2 8
  8
  22  'Tr Blstr-Tr Trk'  1.1   5   7   -765.0000    0.0000   21.3500   2 1 2 8
  8
!
! Side bearings
  23  'Side Brng Ld L '  6.2   4   6    -51.0000   22.4400   25.5000   3 1 14
  24  'Side Brng Ld R '  6.2   4   6    -51.0000  -22.4400   25.5000   3 1 14
  25  'Side Brng Tr L '  6.2   5   7   -765.0000   22.4400   25.5000   3 1 14
  26  'Side Brng Tr R '  6.2   5   7   -765.0000  -22.4400   25.5000   3 1 14
!
! Primary suspension longitudinal connections
  27  'LdTk Lft-Axl Lg'  6.2   6   8      0.0000   39.5000   18.0   1 3 15
```

```
  28  'LdTk Rgt-Ax1 Lg'  6.2   6   8      0.0000  -39.500000 18.00  1 3 15
  29  'LdTk Lft-Ax2 Lg'  6.2   6   9   -102.000000 39.50000  18.0   1 3 15
  30  'LdTk Rgt-Ax2 Lg'  6.2   6   9   -102.0000  -39.500000 18.00  1 3 15
  31  'TrTk Lft-Ax3 Lg'  6.2   7  10   -714.000000 39.50000  18.0   1 3 15
  32  'TrTk Rgt-Ax3 Lg'  6.2   7  10   -714.0000  -39.500000 18.00  1 3 15
      'TrTk Lft-Ax4 Lg'  6.2   7  11   -816.000000 39.50000  18.0   1 3 150
      'TrTk Rgt-Ax4 Lg'  6.2   7  11   -816.0000  -39.500000 18.00  1 3
!
! Primary suspension lateral connections
      'LdTk Lft-Ax1 Lt'  6.2   6   8      0.0000   39.5000   18.0   2 3 16
      'LdTk Rgt-Ax1 Lt'  6.2   6   8      0.0000  -39.500000 18.00  2 3 16
      'LdTk Lft-Ax2 Lt'  6.2   6   9   -102.000000 39.50000  18.0   2 3 16
      'LdTk Rgt-Ax2 Lt'  6.2   6   9   -102.0000  -39.500000 18.00  2 3 16
  39  'TrTk Lft-Ax3 Lt'  6.2   7  10   -714.000000 39.50000  18.0   2 3 160
  40  'TrTk Rgt-Ax3 Lt'  6.2   7  10   -714.0000  -39.500000 18.00  2 3 16
  41  'TrTk Lft-Ax4 Lt'  6.2   7  11   -816.000000 39.50000  18.0   2 3 16
  42  'TrTk Rgt-Ax4 Lt'  6.2   7  11   -816.0000  -39.500000 18.00  2 3 16
!
! Primary suspension vertical connections
  43  'LdTk Lft-Ax1 Vt'  1     6   8      0.0000   39.500000 18.00  3 17
      'LdTk Rgt-Ax1 Vt'  1     6   8      0.0000  -39.500000 18.00  3 17
      'LdTk Lft-Ax2 Vt'  1     6   9   -102.000000 39.50000  18.0   3 17
  46  'LdTk Rgt-Ax2 Vt'  1     6   9   -102.0000  -39.500000 18.00  3 17
  47  'TrTk Lft-Ax3 Vt'  1     7  10   -714.000000 39.50000  18.0   3 17
  48  'TrTk Rgt-Ax3 Vt'  1     7  10   -714.0000  -39.500000 18.00  3 17
  49  'TrTk Lft-Ax4 Vt'  1     7  11   -816.000000 39.50000  18.0   3 17
  50  'TrTk Rgt-Ax4 Vt'  1     7  11   -816.0000  -39.500000 18.00  3 17
!
! Wheel/rail connections
      'Ax 1 Lt Wh/Rail'    4   8          0.0000   29.7500    0.0000   1
  56  'Ax 1 Rt Wh/Rail'    4   8          0.0000  -29.750000  0.0000   10
      'Ax 2 Lt Wh/Rail'    4   9       -102.000000 29.75000   0.0000   20
  58  'Ax 2 Rt Wh/Rail'    4   9       -102.0000  -29.750000  0.0000   2
  59  'Ax 3 Lt Wh/Rail'    4  10       -714.000000 29.75000   0.0000   3
  60  'Ax 3 Rt Wh/Rail'    4  10       -714.0000  -29.750000  0.0000   3
  61  'Ax 4 Lt Wh/Rail'    4  11       -816.000000 29.750000  0.0000   4
  62  'Ax 4 Rt Wh/Rail'    4  11       -816.0000  -29.750000  0.0000   4
!
! Tow rope longitudinal connection
  63  'Dummy Bdy-Grnd '    1   1   0   -408.000000  0.0000    87.0000   1 24


\CHARACTERISTIC DATA
! Centerplate
   8     8    9  1.00E+09 -1.00E+09
! Traction rods
  12          0  1.00E+09 -1.00E+090
  13    16   17  1.00E+09 -1.00E+09
! Side bearings
         8    9  1.00E+09 -1.00E+09  0.00E+00  1.00E+06  1.00E+03  1.70E-01
! Primary suspension
! Journal Box Springs: Stop limits-Stop stiff-Parallel stiff-Parallel
damping-Coeff of friction
  15    18   19  39  -39  1e7  1e6  1e3  0.1
  16    20   21      -39  1e7  1e6  1e3  0.1
  17    22   23  1.00E+09 -1.00E+09
! Tow rope
  24    29   30  1.00E+09 -1.00E+0900
!Airbag shear static stiffness00
  106   110    0   1.0e900    -1.0e900
!Airbag veritcal dAe/dz
  107   112    0   1.0e9      -1.0e900
!Dummy Lat & Long connection00
  108   116   114   1.0e900    -1.0e900
```

```
  109   115    0   1.0e9      -1.0e90
!Dummy airbag roll (for roll moment due to shear)
  110  0    0    1.0e9      -1.0e900
!Long/Lat AB to Bolster00
  111  155    156    1.0e9      -1.0e900
!Airbag vertical reservoir0stiffness and orifice damping
  112  118    119    1.0e900    -1.0e900
!Dynamic long & lat airbag0connection - Spring Damper in Series00
  160  160    0     1.0e9      -1.0e900
  161  0      161   1.0e900    -1.0e900
!Secondary Lateral Damper
  162  0  162  1e9 -1e9
!Secondary Lateral Damper
  163  0  163  1e9 -1e9
!Anti-Roll Bar00
  164 164  0   1e9 -1e9


\WHEEL/RAIL ELEMENT
 2.000E+05 5.000E+02 2.000E+05 5.000E+02
   1      18.000     .F.          0           0
   2      18.000     .F.          0           0
   3      18.000     .F.          0           0
   4      18.000     .F.          0           0


\PWL DATA
!
! Stiff Constraint Stiffness and Damping
  8   2  0.0000E+00  1.0000E+0600
           0.000000    1.00000000
  9   2  0.0000E+00  1.0000E+0300
           0.000000    1.00000000
! Traction Rod Longitudinal Stiffness
 15   2  0.0000E+00  6.0000E+0400
           0.000000    1.000000
!0Traction Rod Shear0Stiffness0
 16   2  0.0000E+00009.6000E+020
           0.000000    1.00000000
!0Traction Rod Shear0Damping ( 5% critical )
 17   2  0.0000E+00004.5000E+010
           0.000000    1.00000000
!0Primary longitudinal stiffness00
 18   4   -124180    -2418000  24180   124180
          -0.197500  -0.097500 0.0975  0.19750
!0Primary longitudinal damping (0.1% of stiffness)
 19   2    0    248
           0    1
!0Primary lateral stiffness00
 20   4   -109167.6  -9167.600 9167.6  109167.60
          -0.29500   -0.19500  0.195   0.295
!0Primary lateral damping (0.1% of stiffness)
 21   2    0    47.0133
           0    1
!0#1 End Primary Coil Spring Vertical Stiffness with static offset (3500
lb/in) doubled (7000)
! 22   2  -14542.3    0
!         0          2.07747
!030% reduction End Primary Coil Spring Vertical Stiffness with static offset00
 22   2  -14542.3    0
        0          2.9675
!0Primary Suspension Vertical Damping ( 5% critical ) doubled00
 23   2   0  72.616
```

```
           0.000000    1.000000
 30   2  0  0
         0  1
!
! Lat/Long Change of area stiffness
  110      2     0.0    425.0
                 0.0      1.0
!Airbag vertical dAe/dz
  112     2   0.0    200.0
            0.0      1.0
!Airbag dummy long and lat
  114     2   0.0      0.0
            0.0      1.0
!Airbag vertical pedestal stiffness
  115    2   -27390   0.0
            0.0      4.957172001
!Long/Lat dynamic shear stiffness - no stiffness
  116    2   0.0      0.0
           0.0      1.0
!Airbag vertical reservoir stiffness
  118    2   -27390  0.0
           0.0      4.82841487
!Orifice damping assuming a 15mm diameter
  119  12   0   27.38345148     109.5338059     246.4510633     438.1352237
        985.8042534     1752.540895     2738.345148     5367.156491
        10953.38059     24645.10633     43813.52237
            0   0.196850394     0.393700787     0.590551181     0.787401575
        1.181102362     1.57480315      1.968503937     2.755905512
        3.937007874     5.905511811     7.874015748
! Very stiff connection of airbag to bolster. long and lat
  155    2    0.0    1e6
              0.0    1.0
  156    2    0.0    1e3
              0.0    1.0
!Long & lat dynamic airbag connection
  160    2    0.0  2500.0
              0.0    1.0
  161    2    0.0  500.0
              0.0    1.0
!Secondary Lateral Damper
  162    2    0.0  50
              0.0    1.0
!Secondary Vertical Damper
  163    2    0.0  25
              0.0    1.0
!Anti-Roll Bar
  164    2    0.0    3e7
              0.0    1.0
```

```
System file (.SYS) for NUCARS Version 2015
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\SYSTEM TITLE
    Journal Spring, Single Level car w/ 4-point secondary air spring
    suspension


\BODY DATA

! ** Car body **
   1    'Car Body        '          -408.00       0.0       64.17
         6  1 2 3 4 5 6              163.17       4.2159E5  1.4352E7  1.4363E7
   2     'AirBag Ld '                -51.000      0.0       37.1
         5   1 2 3 4 6                0.362600    1.70e200 0.0      1.70e2
   3     'AirBag Trl'               -765.000      0.000     37.1
        5   1 2 3 4 6                 0.362600    1.70e2    0.0      1.70e2
!
   400' Lead Bolster  '          -51.000000   0.0000      29.0
    5  1 2 3 4   6                     2.57   3823   122   3869
   5   '0Trail Bolster0'        -765.000000   0.0000      29.0
    5  1 2 3 4   6                     2.57   3823   122   3869
   6   '0Lead Truck     '        -51.000000   0.0000      22.05
    6  1 2 3 4 5 6                     6.57   12009  9783  21268
   7   '00Trail Truck   '       -765.000000   0.0000      22.05
    6  102 3 4 5 600                   6.57   12009  9783  21268
   8   '00Axle Number 1 '          0.0000     0.0000      18.0000
    5  1 2 3 4   6                    12.0800   1.00810E+04  2.7600E+0300
   1.0810E+04
   9   '00Axle Number 200       -102.000000   0.0000      18.0000
    5  1 2 3 4   6                    12.0800   1.0810E+04  2.7600E+0300
   1.0810E+0400
  10   '00Axle Number 300       -714.000000   0.0000      18.0000
    5  1 2 3 4   6                    12.0800   1.0810E+04  2.7600E+0300
   1.00810E+0400
  11   '00Axle Number 4 '       -816.000000   0.0000      18.0000
    5  1 2 3 4   6                    12.0800   1.0810E+04002.7600E+03
   1.0810E+0400


\CONNECTION DATA

! 4-point airbag secondary suspension
!Lead Truck00
!Carbody to Airbag connections00
!2point suspension
  2101  'LdCBtoAirbag Lft'       1002  -5100 39.50  40.69     6  1  2 3 4 5 6
  108  108  109  110 110 110
  2102  'LdCBtoAirbag Rgt'   1.03  1  2  -51   -39.500 40.690    6  1  2 3 4 5 6
  108  108  109  110 110 110
!Airbag to Bolster connections00
  2103  'LdAirbag-Blst Lft'  1.1  2  4  -5100 39.50  33.51     3  1  2  3  111
  111  112
  2104  'LdAirbag-Blst Rgt'  1.1  2  4  -51   -39.500 33.510    3  1  2  3  111
  111  112
!Change of area stiffness and shear00
  2105  'LdCBtoLdBlst Lft'   1.1  1  4  -5100 39.50  37.1      3  1  2  3 106
  106  107
  2106  'LdCBtoLdBlst Rgt'   1.1  1  4  -510          37.1      3  1  2  3 106
       107
!lateral dynamic airbag connection00
  2107  'CB-LdBagLftDyn'      1  1  2  -5100 39.50  37.1      2   160
  2108  'LdBag-LdBlstLftDyn'  1  2  4  -5100 39.50  37.1      2   161
  2109  'CB-LdBagRgtDyn'      1  1  2  -510         37.1      2   160
```

```
  2110  'LdBag-LdBlstRgtDyn'   1  2  4       -39.5   37.1      2   161
!Secondary Lateral Damper
  2111  'SLatDmpLd Lft  '  1  1  4   -57   39.5   37.1  2 162
  2112  'SLatDmpLd Rgt  '  1  1  4   -57  -39.5   37.1  2 162
!Secondary Vertical Damper
  2113  'SVrtDmpLd Lft  '  1  1  4   -45   39.5   37.1  3 163
  2114  'SVrtDmpLd Rgt  '  1  1  4   -45          37.1  3 163
!Anti-Roll Bar
  2115  'Roll Bar Lead  '  1  1  6         0      12.0  4 164
!
!Trail Truck
!Carbody to Airbag connections
!2point suspension
  2201  'TrCBtoAirbag Lft'   1.3  1   3  -765   39.5   40.69    6  1  2 3 4 5
  6  108  108  109  110 110 110
  2202  'TrCBtoAirbag Rgt'   1.3  1   3  -765  -39.5   40.69    6  1  2 3 4 5
  6  108  108  109  110 110 110
!Airbag to Bolster connections
  2203  'TrAirbag-Blst Lft'  1.1  3   5  -765   39.5   33.51    3  1  2  3
  111  111  112
  2204  'TrAirbag-Blst Rgt'  1.1  3   5  -765  -39.5   33.51    3  1  2  3
  111  111  112
!Change of area stiffness and shear
  2205  'TrCBtoTrBlst Lft'   1.1  1   5  -765   39.5   37.1     3  1  2  3 106
  106  107
  2206  'TrCBtoTrBlst Rgt'   1.1  1   5        -39.5   37.1     3  1  2  3 106
  106  107
!lateral dynamic airbag connection
  2207  'CB-TlBagLftDyn'       1  1  3  -765   39.5   37.1      2   160
  2208  'TlBag-TlBlstLftDyn'   1  3  5  -765   39.5   37.1      2   161
  2209  'CB-TlBagRgtDyn'       1  1  3        -39.5   37.1      2   160
  2210  'TlBag-TlBlstRgtDyn'   1  3  5  -765  -39.5   37.1      2   161
!Secondary Lateral Damper
  2211  'SLatDmpTr Lft  '  1  1  5   -759  39.5   37.1  2 162
  2212  'SLatDmpTr Rgt  '  1  1  5   -759 -39.5   37.1  2 162
!Secondary Vertical Damper
  2213  'SVrtDmpTr Lft  '  1  1  5   -771  39.5   37.1  3 163
  2214  'SVrtDmpTr Rgt  '  1  1  5   -771 -39.5   37.1  3 163
!Anti-Roll Trail
  2215  'Roll Bar Trail '  1  1  7         0      12.0  4 164
!
! Traction rods
  17  'Trctn Rd Ld Lft'  1.1   1   4    -51.0000   53.5000   19.6900   3 1 2 3
  12 13 13
  18  'Trctn Rd Ld Rgt'  1.1   1   4    -51.0000  -53.5000   19.6900   3 1 2 3
  12 13 13
  19  'Trctn Rd Tr Lft'  1.1   1   5   -765.0000   53.5000   19.6900   3 1 2 3
  12 13 13
  20  'Trctn Rd Tr Rgt'  1.1   1   5   -765.0000  -53.5000   19.6900   3 1 2 3
  12 13 13
!
! Bolster-truck frame centerplate stiff connections
  21  'Ld Blstr-Ld Trk'  1.1   4   6    -51.0000    0.0000   21.3500   2 1 2 8
  8
  22  'Tr Blstr-Tr Trk'  1.1   5   7   -765.0000    0.0000   21.3500   2 1 2 8
  8
!
! Side bearings
  23  'Side Brng Ld L '  6.2   4   6    -51.0000   22.4400   25.5000   3 1 14
      'Side Brng Ld R '  6.2   4   6    -51.0000  -22.4400   25.5000   3 1 14
      'Side Brng Tr L '  6.2   5   7   -765.0000   22.4400   25.5000   3 1
      'Side Brng Tr R '  6.2   5   7   -765.0000  -22.4400   25.5000   3 1 14
!
! Primary suspension longitudinal connections
```

```
  27 'LdTk Lft-Ax1 Lg'  6.2   6   8      0.0000   39.5000   18.0    1 3
     'LdTk Rgt-Ax1 Lg'0 6.2   6   8      0.0000  -39.500000 18.00   1 3 150
     'LdTk Lft-Ax2 Lg'  6.2   6   9   -102.000000 39.50000  18.0    1 3 15
     'LdTk Rgt-Ax2 Lg'0 6.2   6   9   -102.0000  -39.500000 18.00   1 3 150
  31 'TrTk Lft-Ax3 Lg'  6.2   7  10   -714.000000 39.50000  18.0    1 3 15
  32 'TrTk Rgt-Ax3 Lg'  6.2   7  10   -714.0000  -39.500000 18.00   1 3 15
     'TrTk Lft-Ax4 Lg'  6.2   7  11   -816.000000 39.50000  18.0    1 3 15
     'TrTk Rgt-Ax4 Lg'  6.2   7  11   -816.0000  -39.500000 18.00   1 3 150
!
! Primary suspension lateral connections
     'LdTk Lft-Ax1 Lt'  6.2   6   8      0.0000   39.5000   18.0    2 3 16
     'LdTk Rgt-Ax1 Lt'  6.2   6   8      0.0000  -39.500000 18.00   2 3 16
     'LdTk Lft-Ax2 Lt'  6.2   6   9   -102.000000 39.50000  18.0    2 3 160
  38 'LdTk Rgt-Ax2 Lt'  6.2   6   9   -102.0000  -39.500000 18.00   2 3 16
     'TrTk Lft-Ax3 Lt'  6.2   7  10   -714.000000 39.50000  18.0    2 3 160
  40 'TrTk Rgt-Ax3 Lt'  6.2   7  10   -714.0000  -39.500000 18.00   2 3 16
  41 'TrTk Lft-Ax4 Lt'  6.2   7  11   -816.000000 39.50000  18.0    2 3 160
  42 'TrTk Rgt-Ax4 Lt'  6.2   7  11   -816.0000  -39.500000 18.00   2 3 16
!
! Primary suspension vertical connections
  43 'LdTk Lft-Ax1 Vt'  1     6   8      0.0000   39.5000   18.0    3 17
     'LdTk Rgt-Ax1 Vt'  1     6   8      0.0000  -39.500000 18.00   3 17
     'LdTk Lft-Ax2 Vt'  1     6   9   -102.000000 39.50000  18.0    3 17
  46 'LdTk Rgt-Ax2 Vt'  1     6   9   -102.0000  -39.500000 18.00   3 17
     'TrTk Lft-Ax3 Vt'  1     7  10   -714.000000 39.50000  18.0    3 17
  48 'TrTk Rgt-Ax3 Vt'  1     7  10   -714.0000  -39.500000 18.00   3 17
  49 'TrTk Lft-Ax4 Vt'  1     7  11   -816.000000 39.50000  18.0    3 170
  50 'TrTk Rgt-Ax4 Vt'  1     7  11   -816.0000  -39.500000 18.00   3 17
!
! Wheel/rail connections
  55 'Ax 1 Lt Wh/Rail'    4   8          0.0000   29.7500    0.0000   1
  56 'Ax 1 Rt Wh/Rail'    4   8          0.0000  -29.750000  0.0000   1
     'Ax 2 Lt Wh/Rail'0   4   9       -102.000000 29.75000   0.0000   20
  58 'Ax 2 Rt Wh/Rail'    4   9       -102.0000  -29.750000  0.0000   2
  59 'Ax 3 Lt Wh/Rail'    4   10      -714.000000 29.75000   0.0000   3
  60 'Ax 3 Rt Wh/Rail'0   4   10      -714.0000  -29.750000  0.0000   30
  61 'Ax 4 Lt Wh/Rail'    4   11      -816.000000 29.75000   0.0000   4
  62 'Ax 4 Rt Wh/Rail'    4   11      -816.0000  -29.750000  0.0000   4
!
! Tow rope longitudinal connection
  63 'Dummy Bdy-Grnd '    1   1   0   -408.000000  0.0000   64.1700   1 24


\CHARACTERISTIC DATA
! Centerplate
   8     8    9  1.00E+09 -1.00E+0900
! Traction rods
  12    15    0  1.00E+09 -1.00E+0900
  13    16   17  1.00E+09 -1.00E+09
! Side bearings
  14     8    9  1.00E+09 -1.00E+09  0.00E+00  1.00E+06  1.00E+03  1.70E-01
! Primary suspension
! Journal Box Springs: Stop limits-Stop stiff-Parallel stiff-Parallel
damping-Coeff of friction
  15    18   19  39  -39  1e7  1e6  1e3  0.1
  16    20   21  39  -39  1e7  1e6  1e3  0.1
  17    22   23  1.00E+09 -1.00E+0900
! Tow rope
             30  1.00E+09 -1.00E+0900
!Airbag shear static stiffness00
  106   110    0   1.0e9      -1.0e900
!Airbag veritcal dAe/dz
  107   112    0   1.0e900    -1.0e900
!Dummy Lat & Long connection00
```

```
  108   116   114   1.0e900    -1.0e900
!Airbag veritcal pedestal stiffness - Airbag vertical stiffness00
  109   115    0   1.0e9      -1.0e900
!Dummy airbag roll (for roll moment due to shear)
  110  0    0    1.0e900    -1.0e900
!Long/Lat AB to Bolster00
  111  155    156    1.0e9      -1.0e900
!Airbag vertical reservoir stiffness and orifice damping
  112  118    119    1.0e9      -1.0e900
!Dynamic long & lat airbag connection - Spring Damper in Series00
  160  160    0    1.0e9      -1.0e900
  161  0      161  1.0e9      -1.0e900
!Secondary Lateral Damper
  162  0  162  1e9 -1e9
!Secondary Lateral Damper
  163  0  163  1e9 -1e9
!Anti-Roll Bar00
  164 164  0   1e9 -1e9


\WHEEL/RAIL ELEMENT
 2.000E+05 5.000E+02 2.000E+05 5.000E+02
   1      18.000     .F.          0           0
   2      18.000     .F.          0           0
   3      18.000     .F.          0           0
   4      18.000     .F.          0           0


\PWL DATA
!
! Stiff Constraint Stiffness and Damping
  8   2  0.0000E+00  1.0000E+0600
           0.000000    1.00000000
  9   2  0.0000E+00  1.0000E+0300
           0.000000    1.000000
! Traction Rod Longitudinal Stiffness
 15   2  0.0000E+00  6.0000E+0400
           0.000000    1.000000
!0Traction Rod Shear0Stiffness0
 16   2  0.0000E+00009.6000E+020
           0.000000    1.000000
!0Traction Rod Shear0Damping ( 5% critical )0
 17   2  0.0000E+00004.5000E+010
           0.000000    1.000000
!0Primary longitudinal stiffness00
 18   4   -124180    -2418000  24180   124180
          -0.197500  -0.097500 0.0975  0.19750
! Primary longitudinal damping (0.1% of stiffness)00
      2    0    248
           0    1
!0Primary lateral stiffness00
 20   4   -109167.6  -9167.600 9167.6  109167.60
          -0.29500   -0.19500  0.195   0.295
!0Primary lateral damping (0.1% of stiffness)
 21   2    0    47.0133
           0    1
!0#1 End Primary Coil Spring Vertical Stiffness with static offset (3500
lb/in) doubled (7000)
!02200 2  -879200  0
!         000      1.256
!30% reduction0Primary Coil Spring Vertical Stiffness with static offset (3500
lb/in) doubled00(4900)
 22   2  -8792     0
         0        1.79400
```

```
! Primary Suspension Vertical Damping ( 5% critical ) doubled
 23   2   0  72.616
          0    1
! Dummy Car Longitudinal Stiffness to Ground
 29   2  0.0000E+00  1.0000E+03
           0.000000    1.000000
 30   2  0  0
         0  1
!
! Lat/Long Change of area stiffness
  110      2     0.0    425.0
                 0.0      1.0
!Airbag vertical dAe/dz
  112     2   0.0    200.0
            0.0      1.0
!Airbag dummy long and lat
  114     2   0.0      0.0
            0.0      1.0
!Airbag vertical pedestal stiffness
  115    2   -16140   0.0
            0.0      4.472437977
!Long/Lat dynamic shear stiffness - no stiffness
  116    2   0.0      0.0
           0.0      1.0
!Airbag vertical reservoir stiffness
  118     2   -16140  0.0
           0.0      4.356275304
!Orifice damping assuming a 15mm diameter
  119  12   0   17.88501852     71.54007409     160.9651667     286.1602964
        643.8606668     1144.641185     1788.501852     3505.46363
        7154.007409     16096.51667     28616.02964
            0   0.196850394     0.393700787     0.590551181     0.787401575
        1.181102362     1.57480315      1.968503937     2.755905512
        3.937007874     5.905511811     7.874015748
! Very stiff connection of airbag to bolster. long and lat
  155    2    0.0   1e6
              0.0   1.0
  156    2    0.0   1e3
              0.0   1.0
!Long & lat dynamic airbag connection
  160    2    0.0   1000
              0.0   1.0
  161    2    0.0   500
              0.0   1.0
!Secondary Lateral Damper
  162    2    0.0   50
              0.0   1.0
!Secondary Vertical Damper
  163    2    0.0
              0.0   1.0
!Anti-Roll Bar
  164    2    0.0   3e7
              0.0   1.0
```

```
==========================================

\SYSTEM TITLE
Radial arm truck, bi-level car w/ 4-point secondary air spring suspension


Give the number of0bodies, then for each, list the0number, name, up to 15
characters in single quotes, and c.g. position, relative to0a chosen datum,
followed by the number and list of0degrees of freedom required (from 1=x,
2=y,0 3=z, 4=phi, 5=theta, 6=psi,0 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, & Z00
          No. & DoF List           Mass, Roll, Pitch, & Yaw Inertia00
---------------------------------------------------------------------------
\BODY DATA
   11
   100' Car Body       '       -408.000000   0.0000     87.0000
    6  1 2 3 4 5 6                    282.32   1.1024E6    2.5206E7
    2.4851E7
   2    'AirBag Ld '               -51.000      0.0       37.1
    5  1 2 3 4   6                     0.3626   1.70e200 0.00     1.70e200
   3    'AirBag Trl'              -765.000      0.000     37.1
    5  1 2 3 4   6                     0.3626   1.70e200 0.0      1.70e2
   400' Lead Bolster  '          -51.000000   0.0000     29.0000
    5  1 2 3 4   6                     4.0900   5.1200E+03  4.6000E+02
    5.1200E+03
   5   ' Trail Bolster '       -765.000000   0.0000     29.0000
    5  1 2 3 4   6                     4.0900   5.1200E+03  4.6000E+02
    5.1200E+03
   6   ' Lead Truck    '        -51.000000   0.0000     22.0500
    6  1 2 3 4 5 6                    17.5800   1.7870E+04  1.4120E+0400
    2.8340E+04
   7   ' Trail Truck   '       -765.000000   0.0000     22.0500
    6  1 2 3 4 5 6                    17.5800   1.7870E+04  1.4120E+0400
    2.8340E+04
   8   '00Axle Number 1 '         0.0000      0.0000     18.0000
    5  1 2 3 4   6                    12.0800   1.0810E+04  2.7600E+03
    1.0810E+0400
   9   '00Axle Number 200      -102.000000   0.0000     18.0000
    5  1 2 3 4   6                    12.0800   1.0810E+04  2.7600E+03
    1.0810E+04
  10   ' Axle Number 300       -714.000000   0.0000     18.0000
    5  1 2 3 4   6                    12.0800   1.0810E+04  2.7600E+0300
    1.0810E+0400
  11   ' Axle Number 4 '       -816.000000   0.0000     18.0000
    5  1 2 3 4   6                    12.0800   1.0810E+04  2.7600E+0300
    1.0810E+0400

For all bodies with flexible modes, give the position of the body geometric
center, in the X direction from the datum, its length, and the natural
frequencies (Hz) and damping ratios in twist, vertical, and lateral bending.

  Body #    X-Posn    X-Length00 Nat Frequencies0    Damping Ratios
---------------------------------------------------------------------------

!\FLEXIBLE MODES
   1     -408.00000  1020.000      33.5000000      0.0000000      0.0000000
   0.050  0.000  0.000
   6      -51.00000   116.000      28.3000000      0.0000000      0.0000000
   0.050  0.000  0.000
   7     -765.00000   116.000      28.3000000      0.0000000      0.0000000
```

Give the number of connections, then for each, list the number, name, up to 15 characters in single quotes, a position relative to the chosen datum, numbers for the bodies at each end, 0 for an earth in local track coords., a number indicating the degree of freedom, translational 1,2,3 or rotational 4,5,6, in x,y,z resp., including 2 for lateral wheel motion, and the type:

1 - parallel pair of spring and damper characteristics
2 - series pair of spring and damper characteristics
3 - device with hysteresis between 2 PWL characteristics, e.g. carriage spring or load sensitive suspension
4 - lateral/longitudinal suspension of the wheel on rail
5 - connection force as a history of the distance moved

and the identification number for each of type 1, 2 and 3, the axle number for type 4, input function number for type 5.

Note - single characteristics are treated as parallel pairs with the missing characteristic set to zero in the subsequent table.

```
Conn# ' 15 Char Name  '  Type  Body 1 & 2   Posn in X, Y, & Z   DoF  No.
-------------------------------------------------------------------------------
\CONNECTION DATA
   77
!
!Lead Truckee
!Carbody to Airbag connectionsee
!2point suspensione
  2101  'LdCBtoAirbag Lft'   1.3   1   2   -51ee          40.69     6  1   2 3 4 5 6
  108  108  109  110 110 110
  2102  'LdCBtoAirbag Rgt'   1.3ee1   2   -51ee          40.69     6  1   2 3 4 5 6
  108  108  109  110 110 110
!Airbag to Bolster connectionsee
  2103  'LdAirbag-Blst Lft'  1.1   2   4   -51ee 39.5e  33.51     3  1   2   3   111
  111  112
  2104  'LdAirbag-Blst Rgt'  1.1   2   4   -51ee-39.5ee 33.51e    3  1   2   3   111
  111  112
!Change of area stiffness and shearee
  2105  'LdCBtoLdBlst Lft'   1.1   1   4   -51ee 39.5e  37.1      3  1   2   3 106
  106  107
  2106  'LdCBtoLdBlst Rgt'   1.1   1   4   -51e          37.1      3  1   2   3 106
  106  107
!lateral dynamic airbag connectionee
  2107  'CB-LdBagLftDyn'       1   1   2   -51ee 39.5e  37.1ee    2   160
  2108  'LdBag-LdBlstLftDyn'e  1   2   4         39.5   37.1ee    2   161e
  2109  'CB-LdBagRgtDyn'       1   1   2   -51ee-39.5ee 37.1ee    2   160
  2110  'LdBag-LdBlstRgtDyn'   1   2   4   -51ee-39.5ee 37.1ee    2   161e
!Secondary Lateral Damper
  2111  'SLatDmpLd Lft  '  1   1   4          39.5   37.1  2 162
  2112  'SLatDmpLd Rgt  '  1   1   4                 37.1  2 162e
!Secondary Vertical Damper
  2113  'SVrtDmpLd Lft  '  1   1   4   -45ee 39.5e   37.1  3 163
  2114  'SVrtDmpLd Rgt  '  1   1   4                 37.1  3 163e
!Anti-Roll Baree
  2115  'Roll Bar Lead  '  1   1   6   -51ee 0e      12.0  4 164
!
!Trail Truckee
!Carbody to Airbag connectionsee
!2point suspensione
  2201  'TrCBtoAirbag Lft'        lee 3  -765            40.69    6  1   2 3 4 5
  6  108   108  109  110 110 110
  2202  'TrCBtoAirbag Rgt'   1.3  lee 3  -765   -39.5e   40.69    6  1   2 3 4 5
  6  108   108  109  110 110 110
```

```
!Airbag to Bolster connections
  2203  'TrAirbag-Blst Lft'  1.1  3   5  -765   39.5   33.51    3  1  2  3
  111  111  112
  2204  'TrAirbag-Blst Rgt'  1.1  3   5  -765  -39.5   33.51    3  1  2  3
  111  111  112
!Change of area stiffness and shear
  2205  'TrCBtoTrBlst Lft'   1.1  1   5  -765   39.5   37.1     3  1  2  3 106
  106  107
  2206  'TrCBtoTrBlst Rgt'   1.1  1   5  -765  -39.5   37.1     3  1  2  3 106
  106  107
!lateral dynamic airbag connection
  2207  'CB-TlBagLftDyn'       1  1  3  -765   39.5   37.1      2   160
  2208  'TlBag-TlBlstLftDyn'   1  3  5  -765   39.5   37.1      2   161
  2209  'CB-TlBagRgtDyn'       1  1  3  -765  -39.5   37.1      2   160
  2210  'TlBag-TlBlstRgtDyn'   1  3  5        -39.5   37.1      2   161
!Secondary Lateral Damper
  2211  'SLatDmpTr Lft  '  1  1  5   -759         37.1  2 162
  2212  'SLatDmpTr Rgt  '  1  1  5        -39.5   37.1  2 162
!Secondary Vertical Damper
  2213  'SVrtDmpTr Lft  '  1  1  5   -771         37.1  3 163
  2214  'SVrtDmpTr Rgt  '  1  1  5   -771 -39.5   37.1  3 163
!Anti-Roll Trail
  2215  'Roll Bar Trail '  1  1  7   -765  0      12.0  4 164
!
!  15  'Latrl Damper Ld'    1   1   4    -51.0000    0.0000   35.5600   2 11
!  16  'Latrl Damper Tr'    1   1   5   -765.0000    0.0000   35.5600   2 11
      'Trctn Rd Ld Lft'  1.1   1   4    -51.0000   53.5000   19.6900   3 1 2 3
  12 13 13
  18  'Trctn Rd Ld Rgt'  1.1   1   4    -51.0000  -53.5000   19.6900   3 1 2 3
  12 13 13
  19  'Trctn Rd Tr Lft'  1.1   1   5   -765.0000   53.5000   19.6900   3 1 2 3
  12 13 13
  20  'Trctn Rd Tr Rgt'  1.1   1   5   -765.0000  -53.5000   19.6900   3 1 2 3
  12 13 13
  21  'Ld Blstr-Ld Trk'  1.1   4   6    -51.0000    0.0000   21.3500   2 1 2 8
  8
  22  'Tr Blstr-Tr Trk'  1.1   5   7   -765.0000    0.0000   21.3500   2 1 2 8
  8
  23  'Side Brng Ld L '  6.2   4   6    -51.0000   22.4400   25.5000   3 1 14
  24  'Side Brng Ld R '  6.2   4   6    -51.0000  -22.4400   25.5000   3 1 14
  25  'Side Brng Tr L '  6.2   5   7   -765.0000   22.4400   25.5000   3 1 14
  26  'Side Brng Tr R '  6.2   5   7   -765.0000  -22.4400   25.5000   3 1 14
  27  'Ld Trk Lft-Ax 1'  1.1   6   8      0.0000   39.5000   31.1000   2 2 3
  16 18
  28  'Ld Trk Rgt-Ax 1'  1.1   6   8      0.0000  -39.5000   31.1000   2 2 3
  16 18
  29  'Ld Trk Lft-Ax 2'  1.1   6   9   -102.0000   39.5000   31.1000   2 2 3
  16 18
  30  'Ld Trk Rgt-Ax 2'  1.1   6   9   -102.0000  -39.5000   31.1000   2 2 3
  16 18
  31  'Tr Trk Lft-Ax 3'  1.1   7  10   -714.0000   39.5000   31.1000   2 2 3
  15 17
  32  'Tr Trk Rgt-Ax 3'  1.1   7  10   -714.0000  -39.5000   31.1000   2 2 3
     17
      'Tr Trk Lft-Ax 4'  1.1   7  11   -816.0000   39.5000   31.1000   2 2 3
  15 17
  34  'Tr Trk Rgt-Ax 4'  1.1   7  11   -816.0000  -39.5000   31.1000   2 2 3
  15 17
      'Ld Trk Lft-Ax 1'   -1   6   8     -0.0100   39.5000   30.1558
                                          0.0100   39.5000   30.1442   1 20
  36  'Ld Trk Rgt-Ax 1'   -1   6   8     -0.0100  -39.5000   30.1558
                                          0.0100  -39.5000   30.1442   1 20
      'Ld Trk Lft-Ax      -1   6   9   -101.9900   39.5000   30.1558
                                       -102.0100   39.5000   30.1442   1 20
```

```
     'Ld Trk Rgt-Ax 2'   -1    6    9    -101.990099-39.500099 30.15589
                                         -102.010099-39.500099 30.14429   1 20
     'Ld Trk Lft-Ax 3'   -199 7   109    -714.010099 39.500099 30.42599
                                         -713.990099 39.500099 30.41419   1 19
 40  'Ld Trk Rgt-Ax 3'   -1    7   10    -714.010099-39.500099 30.42599
                                         -713.990099-39.500099 30.41419   1 19
     'Ld Trk Lft-Ax 4'   -199 79  11     -815.990099 39.500099 30.42599
                                         -816.010099 39.500099 30.41419   1 19
     'Ld Trk Rgt-Ax 4'   -1    7   11    -815.990099-39.500099 30.42599
                                         -816.010099-39.500099 30.41419   1 19
 43  'Ld Trk Lft-Ax 1'  1.1    6    8     -19.690099 39.500099 18.79009   2 1 29
 21 22
     'Ld Trk Rgt-Ax 1'  1.1    6    8     -19.690099-39.500099 18.79009   2 1 2
 21 229
     'Ld Trk Lft-Ax 2'  1.1    6    9     -82.310099 39.50009  18.7900    2 1 2
 21 22
     'Ld Trk Rgt-Ax 2'  1.1    6    9     -82.310099-39.500099 18.79009   2 1 2
 21 22
     'Tr Trk Lft-Ax 3'  1.1    7   10    -733.690099 39.50009  18.7900    2 1 2
 21 22
 48  'Tr Trk Rgt-Ax 3'  1.1    7   10    -733.690099-39.500099 18.790099 2 1 29
 21 22
     'Tr Trk Lft-Ax 4'  1.1    7   11    -796.310099 39.50009  18.790099 2 1 29
 21 22
 50  'Tr Trk Rgt-Ax 4'  1.1    7   11    -796.310099-39.500099 18.79009   2 1 2
 21 22
     'Ld Trk-Ax 1    '   1     6    8     -19.690099  0.0000   18.7900    4 23
     'Ld Trk-Ax 2    '   1     6    9     -82.310099  0.0000   18.7900    4 23
     'Tr Trk-Ax 3    '   1     7   10    -733.690099  0.0000   18.7900    4 23
     'Tr Trk-Ax 4    '   1     7   11    -796.310099  0.0000   18.7900    4 23
     'Ax 1 Lt Wh/Rail'9  4     8             0.0000   29.7500   0.0000    1
 56  'Ax 1 Rt Wh/Rail'   4     8             0.0000  -29.750099  0.0000   1
 57  'Ax 2 Lt Wh/Rail'9  4     9         -102.000099 29.750099  0.0000    2
     'Ax 2 Rt Wh/Rail'   4     9         -102.000099-29.750099  0.0000    2
     'Ax 3 Lt Wh/Rail'   4    10         -714.000099 29.750099  0.0000    3
 60  'Ax 3 Rt Wh/Rail'   4    10         -714.000099-29.750099  0.0000    39
 61  'Ax 4 Lt Wh/Rail'9  4    11         -816.000099 29.750099  0.0000    4
     'Ax 4 Rt Wh/Rail'   4    11         -816.000099-29.750099  0.0000    4
     'Dummy Bdy-Grnd99   1     1    0    -408.000099  0.000099 87.0000    1 24
```

```
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
!
  8      8     9  1.00E+09 -1.00E+09
! 11      0    14  1.00E+09 -1.00E+09
 12     15     0  1.00E+09 -1.00E+09
 13     16    17  1.00E+09 -1.00E+0999
 14      8     9  1.00E+09 -1.00E+09  0.00E+00  1.00E+06  1.00E+03  1.70E-01
 15     18     0  1.00E+09 -1.00E+0999
 16     19     0  1.00E+09 -1.00E+09
 17     20    21  0.00E+00 -1.00E+0999
 18     22    21  0.00E+00 -1.00E+0999
 19     23     0  1.00E+09 -1.00E+09
 20     24     0  1.00E+09 -1.00E+09
 21     25     0  1.00E+09 -1.00E+09
 22     26    27  1.00E+09 -1.00E+09
 23     28     0  1.00E+09 -1.00E+09
 24     29     0  1.00E+09 -1.00E+09
```

```
!
!Airbag shear static stiffness00
  106   110    0   1.0e900    -1.0e900
!Airbag veritcal dAe/dz
  107   112    0   1.0e9      -1.0e900
!Dummy Lat & Long connection00
  108   116   114   1.0e900    -1.0e900
!Airbag veritcal pedestal stiffness - Airbag vertical stiffness00
  109   115    0   1.0e9      -1.0e900
!Dummy airbag roll (for roll moment due to shear)
  110  0     0    1.0e900    -1.0e900
!Long/Lat AB to Bolster00
  111  155    156    1.0e9      -1.0e900
!Airbag vertical reservoir stiffness and orifice damping
  112  118    119    1.0e9      -1.0e900
!Dynamic long & lat airbag connection - Spring Damper in Series00
  160  160    0    1.0e9      -1.0e900
  161  0      161  1.0e9      -1.0e900
!Secondary Lateral Damper
  162  0  162  1e9 -1e9
!Secondary Lateral Damper
  163  0  163  1e9 -1e9
!Anti-Roll Bar00
  164 164  0   1e9 -1e9
```

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
 2.000E+05 5.000E+02 2.000E+05 5.000E+02
   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, N or N-m, over abscissa, meters 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
! Stiff Constraint Stiffness and Damping
  8    2  0.0000E+00  1.0000E+06
          0.000000    1.000000
  9    2  0.0000E+00  1.0000E+03
          0.000000    1.000000
! Lateral Damper Characteristic ( both sides combined )
! 14  12  0.0000E+00  2.7700E+02  6.7700E+02  1.2310E+03  1.7850E+03
2.5240E+03  3.2000E+03
!         3.7540E+03  4.0000E+03  4.4000E+03  4.6760E+03  8.0000E+03
!           0.000000    1.625000    3.250000    4.875000    6.500000
8.125000    9.750000
!          11.37500000 13.00000000 16.2500000  19.500000   65.000000
!0Traction Rod Longitudinal Stiffness00
```

```
              0.000000    1.000000
! Traction Rod Shear Stiffness
 16   2  0.0000E+00  9.6000E+02
              0.000000    1.000000
! Traction Rod Shear Damping ( 5% critical )
 17   2  0.0000E+00  4.5000E+01
              0.000000    1.000000
! #1 End Primary Coil Spring Lateral Shear Stiffness
 18   2  0.0000E+00  2.5010E+03
              0.000000    1.000000
! #2 End Primary Coil Spring Lateral Shear Stiffness
 19   2  0.0000E+00  2.0720E+03
              0.000000    1.000000
! #1 End Primary Coil Spring Vertical Stiffness
 20  10 -25617.642  -22293.642  -21179.642  -20061.642  -18942.642  -17813.642
 -16674.642  -14445.642  -10945.642  -2863.642
            -1.063000   -0.945000   -0.866000   -0.768000   -0.650000   -
            0.473000   -0.236000
             0.334000    1.220000    3.662000
! Primary Suspension Vertical Damping ( 5% critical )
 21   2  0.0000E+00  1.2500E+01
              0.000000    1.000000
! #2 End Primary Coil Spring Vertical Stiffness
 22  10 -27780.981   -24455.981   -23342.981   -22224.981   -21104.981   -
 19976.981   -18837.981
         -16608.981   -13108.981   -5025.981
            -1.614000   -1.496000   -1.417000   -1.319000   -1.201000   -
            1.024000   -0.787000
            -0.217000    0.669000    3.111000
! #1 End Primary Vertical & Longitudinal Stiffness (incline spring=shear
effect)
 23   2  0.0000E+00  4.2190E+03
              0.000000    1.000000
! #2 End Primary Vertical & Longitudinal Stiffness (incline spring=shear
effect)
 24   2  0.0000E+00  3.4870E+03
              0.000000    1.000000
! Primary Trailing Arm Bushing Longitudinal Stiffness
 25   2  0.0000E+00  1.7000E+05
              0.000000    1.000000
! Primary Trailing Arm Bushing Lateral Stiffness
 26   2  0.0000E+00  5.2000E+04
              0.000000    1.000000
! Primary Trailing Arm Bushing Lateral Damping ( 5% critical )
 27   2  0.0000E+00  5.9000E+01
              0.000000    1.000000
! Radial Arm Roll Stiffness
 28   2  0.0000E+00  8.5400E+05
              0.000000    1.000000
! Dummy Car Longitudinal Stiffness to Ground
 29   2  0.0000E+00  1.0000E+03
              0.000000    1.000000
!
! Lat/Long Change of area stiffness
  110      2     0.0    425.0
                 0.0      1.0
!Airbag vertical dAe/dz
  112     2   0.0    200.0
            0.0      1.0
!Airbag dummy long and lat
  114     2   0.0      0.0
            0.0      1.0
!Airbag vertical pedestal stiffness
```

```
!Long/Lat dynamic shear stiffness - no stiffness
  116    2   0.0      0.0
            0.0      1.0
!Airbag vertical reservoir stiffness
  118    2   -27390  0.0
            0.0      4.82841487
!Orifice damping assuming a 15mm diameter
  119  12   0   27.38345148     109.5338059     246.4510633     438.1352237
        985.8042534     1752.540895     2738.345148     5367.156491
        10953.38059     24645.10633     43813.52237
            0   0.196850394     0.393700787     0.590551181     0.787401575
        1.181102362     1.57480315      1.968503937     2.755905512
        3.937007874     5.905511811     7.874015748
! Very stiff connection of airbag to bolster. long and lat
  155   2   0.0   1e6
            0.0   1.0
  156   2   0.0   1e3
            0.0   1.0
!Long & lat dynamic airbag connection
  160   2   0.0  2500.0
            0.0   1.0
  161   2   0.0  500.0
            0.0   1.0
!Secondary Lateral Damper
  162   2   0.0  50
            0.0   1.0
!Secondary Vertical Damper
  163   2   0.0  25
            0.0   1.0
!Anti-Roll Bar
  164   2   0.0   3e7
            0.0   1.0
```

```
=========================================

\SYSTEM TITLE
Radial arm truck, single-level car w/ 4-point secondary air spring suspension


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, & Z00
          No. & DoF List             Mass, Roll, Pitch, & Yaw Inertia00
-------------------------------------------------------------------------
\BODY DATA
   11
   1  ' Car Body0      '         -408.000000   0.0000     64.17
    6  1 2 3 4 5 6                       163.17      4.2159E5  1.4352E7
    1.4363E700
   2    'AirBag Ld00                 -51.000       0.0       37.1
    5  1 2 3 4   6                      0.0362600 1.70e2    0.0      1.70e2
   3    'AirBag Trl'               -765.000        0.0       37.1
    5  1 2 3 4   6                      0.362600 1.70e2    0.0      1.70e2
   4  ' Lead Bolster  '           -51.000000    0.0000     29.0000
    5  1 2 3 4   6                      4.0900   5.1200E+03  4.6000E+02
    5.1200E+03
   500' Trail Bolster '          -765.000000   0.0000     29.0000
    5  1 2 3 4   6                      4.0900   5.1200E+03  4.6000E+02
    5.1200E+03
   600' Lead Truck     '          -51.000000   0.0000     22.0500
    6  1 2 3 4 5 6                     17.5800   1.7870E+04  1.4120E+0400
    2.8340E+04
   700' Trail Truck    '         -765.000000   0.0000     22.0500
    6  1 2 3 4 5 6                     17.5800   1.7870E+04  1.4120E+04
    2.8340E+04
   8  '00Axle Number 1 '            0.0000     0.0000     18.0000
    5  1 2 3 4   6                     12.0800   1.0810E+04  2.7600E+0300
    1.0810E+04
   9  '00Axle Number 2 '         -102.000000   0.0000     18.0000
    5  1 2 3 4   6                     12.0800   1.0810E+04  2.7600E+0300
    1.0810E+04
  10  '00Axle Number 3 '         -714.000000   0.0000     18.0000
    5  1 2 3 4   6                     12.0800   1.0810E+04  2.7600E+0300
    1.0810E+0400
  11  '00Axle Number 4 '         -816.000000   0.0000     18.0000
    5  1 2 3 4   6                     12.0800   1.0810E+04  2.7600E+0300
    1.0810E+0400

For all bodies with flexible modes, give the position of the body geometric
center, in the X direction from the datum, its length, and the natural
frequencies (Hz) and damping ratios in twist, vertical, and lateral bending.

  Body #    X-Posn00  X-Length00 Nat Frequencies     Damping Ratios
-------------------------------------------------------------------------

!\FLEXIBLE MODES
   1      -408.00000  1020.000      33.5000000     0.0000000      0.0000000
   0.050  0.000  0.000
   6       -51.00000   116.000      28.3000000     0.0000000      0.0000000
   0.050  0.000  0.000
   7     -765.00000   116.000      28.3000000     0.0000000      0.0000000
```

Give the number of connections, then for each, list the number, name, up to 15 characters in single quotes, a position relative to the chosen datum, numbers for the bodies at each end, 0 for an earth in local track coords., a number indicating the degree of freedom, translational 1,2,3 or rotational 4,5,6, in x,y,z resp., including 2 for lateral wheel motion, and the type:

1 - parallel pair of spring and damper characteristics
2 - series pair of spring and damper characteristics
3 - device with hysteresis between 2 PWL characteristics, e.g. carriage spring or load sensitive suspension
4 - lateral/longitudinal suspension of the wheel on rail
5 - connection force as a history of the distance moved

and the identification number for each of type 1, 2 and 3, the axle number for type 4, input function number for type 5.

Note - single characteristics are treated as parallel pairs with the missing characteristic set to zero in the subsequent table.

```
Conn# ' 15 Char Name   '  Type  Body 1 & 2   Posn in X, Y, & Z   DoF  No.
-------------------------------------------------------------------------
\CONNECTION DATA

!
!Lead Truckee
!Carbody to Airbag connectionsee
!2point suspension
  2101  'LdCBtoAirbag Lft'   1.3  1  2  -51ee 39.5e  40.69     6  1  2 3 4 5 6
  108  108  109  110 110 110
  2102  'LdCBtoAirbag Rgt'   1.3  1  2  -51  -39.5ee 40.69e    6  1  2 3 4 5 6
  108  108  109  110 110 110
!Airbag to Bolster connectionsee
  2103  'LdAirbag-Blst Lft'  1.1  2  4  -51ee        33.51     3  1  2  3  111
  111  112
  2104  'LdAirbag-Blst Rgt'  1.1  2  4  -51  -39.5ee 33.51e    3  1  2  3  111
  111  112
!Change of area stiffness and shearee
  2105  'LdCBtoLdBlst Lft'   1.1  1  4  -51ee        37.1      3  1  2  3 106
  106  107
  2106  'LdCBtoLdBlst Rgt'   1.1  1  4  -51  -39.5ee 37.1e     3  1  2  3 106
  106  107
!lateral dynamic airbag connectionee
  2107  'CB-LdBagLftDyn'        1  1  2  -51ee        37.1      2   160
  2108  'LdBag-LdBlstLftDyn'e  1  2  4  -51ee        37.1      2   161e
  2109  'CB-LdBagRgtDyn'        1  1  2  -51  -39.5ee 37.1e     2   160
  2110  'LdBag-LdBlstRgtDyn'   1  2  4  -51  -39.5ee 37.1e     2   161
!Secondary Lateral Damper
  2111  'SLatDmpLd Lftee'  1  1  4   -57ee 39.5e  37.1  2 162
  2112  'SLatDmpLd Rgte '  1  1  4         -39.5ee 37.1  2 162e
!Secondary Vertical Damper
  2113  'SVrtDmpLd Lft  '  1  1  4   -45ee         37.1  3 163
  2114  'SVrtDmpLd Rgt  '  1  1  4         -39.5ee 37.1  3 163e
!Anti-Roll Baree
  2115  'Roll Bar Lead  '  1  1  6   -51ee 0e      12.0  4 164
!
!Trail Truckee
!Carbody to Airbag connectionsee
!2point suspensione
  2201  'TrCBtoAirbag Lft'   1.3  1    3                 40.69    6  1  2 3 4 5
  6  108  108  109  110 110 110
  2202  'TrCBtoAirbag Rgt'   1.3  1ee 3  -765e           40.69    6  1  2 3 4 5
     108  108  109  110 110 110
!Airbag to Bolster connectionsee
  2203  'TrAirbag-Blst Lft'ee1.1  3    5                 33.51    3  1  2  3
```

```
    _ _  _
  111  111  112
  2204  'TrAirbag-Blst Rgt'  1.1  3   5  -765  -39.5   33.51    3  1  2  3
  111  111  112
!Change of area stiffness and shear
  2205  'TrCBtoTrBlst Lft'   1.1  1   5  -765   39.5   37.1     3  1  2  3 106
  106  107
  2206  'TrCBtoTrBlst Rgt'   1.1  1   5  -765  -39.5   37.1     3  1  2  3 106
  106  107
!lateral dynamic airbag connection
  2207  'CB-TlBagLftDyn'       1  1  3  -765   39.5   37.1      2   160
  2208  'TlBag-TlBlstLftDyn'   1  3  5  -765   39.5   37.1      2   161
  2209  'CB-TlBagRgtDyn'       1  1  3  -765  -39.5   37.1      2   160
  2210  'TlBag-TlBlstRgtDyn'   1  3  5  -765  -39.5   37.1      2   161
!Secondary Lateral Damper
  2211  'SLatDmpTr Lft  '  1  1  5        39.5   37.1  2 162
  2212  'SLatDmpTr Rgt  '  1  1  5   -759 -39.5   37.1  2 162
!Secondary Vertical Damper
  2213  'SVrtDmpTr Lft  '  1  1  5   -771  39.5   37.1  3 163
  2214  'SVrtDmpTr Rgt  '  1  1  5   -771 -39.5   37.1  3 163
!Anti-Roll Trail
  2215  'Roll Bar Trail '  1  1  7   -765  0      12.0  4 164
!
!  15  'Latrl Damper Ld'    1   1   4    -51.0000    0.0000   35.5600   2 11
!  16  'Latrl Damper Tr'    1   1   5   -765.0000    0.0000   35.5600   2 11
  17  'Trctn Rd Ld Lft'  1.1   1   4    -51.0000   53.5000   19.6900   3 1 2 3
  12 13 13
  18  'Trctn Rd Ld Rgt'  1.1   1   4    -51.0000  -53.5000   19.6900   3 1 2 3
  12 13 13
  19  'Trctn Rd Tr Lft'  1.1   1   5   -765.0000   53.5000   19.6900   3 1 2 3
  12 13 13
  20  'Trctn Rd Tr Rgt'  1.1   1   5   -765.0000  -53.5000   19.6900   3 1 2 3
  12 13 13
  21  'Ld Blstr-Ld Trk'  1.1   4   6    -51.0000    0.0000   21.3500   2 1 2 8
  8
  22  'Tr Blstr-Tr Trk'  1.1   5   7   -765.0000    0.0000   21.3500   2 1 2 8
  8
  23  'Side Brng Ld L '  6.2   4   6    -51.0000   22.4400   25.5000   3 1 14
  24  'Side Brng Ld R '  6.2   4   6    -51.0000  -22.4400   25.5000   3 1 14
  25  'Side Brng Tr L '  6.2   5   7   -765.0000   22.4400   25.5000   3 1 14
  26  'Side Brng Tr R '  6.2   5   7   -765.0000  -22.4400   25.5000   3 1 14
  27  'Ld Trk Lft-Ax 1'  1.1   6   8      0.0000   39.5000   31.1000   2 2 3
  16 18
  28  'Ld Trk Rgt-Ax 1'  1.1   6   8      0.0000  -39.5000   31.1000   2 2 3
  16 18
  29  'Ld Trk Lft-Ax 2'  1.1   6   9   -102.0000   39.5000   31.1000   2 2 3
  16 18
  30  'Ld Trk Rgt-Ax 2'  1.1   6   9   -102.0000  -39.5000   31.1000   2 2 3
  16 18
      'Tr Trk Lft-Ax     1.1   7  10   -714.0000   39.5000   31.1000   2 2 3
  15
      'Tr Trk Rgt-Ax 3'  1.1   7  10   -714.0000  -39.5000   31.1000   2 2 3
  15 17
      'Tr Trk Lft-Ax 4'  1.1   7  11   -816.0000   39.5000   31.1000   2 2 3

      'Tr Trk Rgt-Ax 4'  1.1   7  11   -816.0000  -39.5000   31.1000   2 2 3
     17
      'Ld Trk Lft-Ax 1'   -1   6   8     -0.0100   39.5000   30.1558
                                          0.0100   39.5000   30.1442   1 20
  36  'Ld Trk Rgt-Ax 1'   -1   6   8     -0.0100  -39.5000   30.1558
                                          0.0100  -39.5000   30.1442   1 20
      'Ld Trk Lft-Ax 2'   -1   6   9   -101.9900   39.5000   30.1558
                                       -102.0100   39.5000   30.1442   1 20
  38  'Ld Trk Rgt-Ax 2'   -1   6   9   -101.9900  -39.5000   30.1558
                                       -102.0100  -39.5000   30.1442   1 20
```

```
  39  'Ld Trk Lft-Ax 3'   -1    7  10   -714.0100   39.5000   30.4259
                                        -713.9900   39.5000   30.4141   1 19
  40  'Ld Trk Rgt-Ax 3'   -1    7  10   -714.0100  -39.5000   30.4259
                                        -713.9900  -39.5000   30.4141   1 19
  41  'Ld Trk Lft-Ax 4'   -1    7  11   -815.9900   39.5000   30.4259
                                        -816.0100   39.5000   30.4141   1 19
  42  'Ld Trk Rgt-Ax 4'   -1    7  11   -815.9900  -39.5000   30.4259
                                        -816.0100  -39.5000   30.4141   1 19
  43  'Ld Trk Lft-Ax 1'  1.1    6   8    -19.6900   39.5000   18.7900   2 1 2
  21 22
      'Ld Trk Rgt-Ax 1'  1.1    6   8    -19.6900  -39.5000   18.7900   2 1 2
     22
      'Ld Trk Lft-Ax 2'  1.1    6   9    -82.3100   39.5000   18.7900   2 1 2
     22
      'Ld Trk Rgt-Ax 2'  1.1    6   9    -82.3100  -39.5000   18.7900   2 1 2
     22
      'Tr Trk Lft-Ax 3'  1.1    7  10   -733.6900   39.5000   18.7900   2 1 2
  21 22
  48  'Tr Trk Rgt-Ax 3'  1.1    7  10   -733.6900  -39.5000   18.7900   2 1 2
  21 22
      'Tr Trk Lft-Ax 4'  1.1    7  11   -796.3100   39.5000   18.7900   2 1 2
  21 22
  50  'Tr Trk Rgt-Ax 4'  1.1    7  11   -796.3100  -39.5000   18.7900   2 1 2
  21 22
  51  'Ld Trk-Ax 1     '   1    6   8    -19.6900    0.0000   18.7900   4 23
      'Ld Trk-Ax 2     '   1    6   9    -82.3100    0.0000   18.7900   4 23
  53  'Tr Trk-Ax 3     '   1    7  10   -733.6900    0.0000   18.7900   4 23
  54  'Tr Trk-Ax 4     '   1    7  11   -796.3100    0.0000   18.7900   4 23
  55  'Ax 1 Lt Wh/Rail'    4    8           0.0000   29.7500    0.0000   1
      'Ax 1 Rt Wh/Rail'    4    8           0.0000  -29.7500    0.0000   1
      'Ax 2 Lt Wh/Rail'    4    9        -102.0000   29.7500    0.0000   2
      'Ax 2 Rt Wh/Rail'    4    9        -102.0000  -29.7500    0.0000   2
      'Ax 3 Lt Wh/Rail'    4   10        -714.0000   29.7500    0.0000   3
  60  'Ax 3 Rt Wh/Rail'    4   10        -714.0000  -29.7500    0.0000   3
  61  'Ax 4 Lt Wh/Rail'    4   11        -816.0000   29.7500    0.0000   4
  62  'Ax 4 Rt Wh/Rail'    4   11        -816.0000  -29.7500    0.0000   4
  63  'Dummy Bdy-Grnd '    1    1   0   -408.0000    0.0000   64.1700   1 24
```

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
   8      8    9  1.00E+09 -1.00E+09
!  11      0   14  1.00E+09 -1.00E+09
  12     15    0  1.00E+09 -1.00E+09
  13     16   17  1.00E+09 -1.00E+09
  14      8    9  1.00E+09 -1.00E+09  0.00E+00  1.00E+06  1.00E+03  1.70E-01
  15     18    0  1.00E+09 -1.00E+09
  16     19    0  1.00E+09 -1.00E+09
  17     20   21  0.00E+00 -1.00E+09
  18     22   21  0.00E+00 -1.00E+09
  19     23    0  1.00E+09 -1.00E+09
  20     24    0  1.00E+09 -1.00E+09
  21     25    0  1.00E+09 -1.00E+09
  22     26   27  1.00E+09 -1.00E+09
  23     28    0  1.00E+09 -1.00E+09
  24     29    0  1.00E+09 -1.00E+09
!  25      0    0  1.00E+09 -1.00E+09
!Airbag shear static stiffness
  106   110    0   1.0e9      -1.0e9
```

```
  107   112    0   1.0e900    -1.0e900
!Dummy Lat & Long connection00
  108   116   114   1.0e900    -1.0e900
!Airbag veritcal pedestal stiffness - Airbag vertical stiffness00
  109   115    0   1.0e9      -1.0e900
!Dummy airbag roll (for roll moment due to shear)
  110  0     0    1.0e900    -1.0e900
!Long/Lat AB to Bolster00
  111  155    156    1.0e900    -1.0e900
!Airbag vertical reservoir stiffness and orifice damping
  112  118    119    1.0e9      -1.0e900
!Dynamic long & lat airbag connection - Spring Damper in Series00
  160  160     0    1.0e900    -1.0e900
  161  0       161  1.0e900    -1.0e900
!Secondary Lateral Damper
  162  0  162  1e9 -1e9
!Secondary Lateral Damper
  163  0  163  1e9 -1e9
!Anti-Roll Bar00
  164 164  0   1e9 -1e9
```

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
 2.000E+05 5.000E+02 2.000E+05 5.000E+02
   1       18.000      .F.          0           0
   2       18.000      .F.          0           0
   3       18.000      .F.          0           0
   4       18.00000    .F.          0           0
```

For each piecewise linear function, list the identification number, the number of break points, and the ordinate, N or N-m, over abscissa, meters 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
!
! Stiff Constraint Stiffness and Damping
  8    2  0.0000E+00  1.0000E+0600
            0.000000    1.00000000
  9    2  0.0000E+00  1.0000E+0300
            0.000000    1.00000000
! Lateral Damper Characteristic00 both sides combined )
! 14   12   0.0000E+00   2.7700E+02   6.7700E+02   1.2310E+03   1.7850E+03
2.5240E+03   3.2000E+03
!          3.7540E+03   4.0000E+03   4.4000E+03   4.6760E+03   8.0000E+03
!            0.000000     1.625000     3.250000     4.875000     6.500000
8.125000     9.750000
!           11.375000    13.000000    16.250000    19.500000    65.000000
!00Traction Rod Longitudinal Stiffness00
 15    2  0.0000E+00  6.0000E+04
            0.000000    1.000000
```

```
!00Traction Rod Shear Stiffness00
 16   2  0.0000E+00  9.6000E+0200
          0.000000    1.000000
!00Traction Rod Shear Damping ( 5% critical00
 17   2  0.0000E+00  4.5000E+0100
          0.000000    1.000000
! #1 End0Primary Coil Spring Lateral Shear Stiffness0
 18   2000.0000E+00  2.5010E+0300
          0.000000    1.000000
!00#2 End0Primary Coil Spring Lateral Shear Stiffness0
 19   2000.0000E+00  2.0720E+0300
          0.000000    1.000000
!0 #1 End0Primary Coil Spring Vertical Stiffness0
 20  10   -19867.3100 -16558.5800 -15444.5800 -14326.5800 -13207.5800 -
 12078.58   -10939.5800
           -8710.5800  -5210.5800   2871.42
          -1.06300000 -0.94500000 -0.86600000 -0.76800000 -0.65000000 -
          0.47300000 -0.23600000
           0.334000    1.22000000  3.662000
!00Primary Suspension Vertical Damping ( 5% critical00
 21   2  0.0000E+00  1.2500E+01
          0.000000    1.000000
!00#2 End Primary Coil Spring Vertical Stiffness00
 22  10 -22030.653  -18705.653  -17592.653  -16474.65300-15354.653  -14226.65300
 -13087.65300
         -10858.65300 -7358.65300   724.347
          -1.61400000 -1.49600000 -1.41700000 -1.31900000 -1.20100000 -
          1.02400000 -0.78700000
          -0.21700000  0.66900000  3.111000
!00#1 End Primary Vertical & Longitudinal Stiffness (incline spring=shear00
effect)
 23   2  0.0000E+00  4.2190E+0300
          0.000000    1.000000
!00#2 End Primary Vertical & Longitudinal Stiffness (incline spring=shear00
effect)
 24   2  0.0000E+00  3.4870E+0300
          0.000000    1.00000000
!00Primary Trailing Arm Bushing Longitudinal Stiffness00
 25   2  0.0000E+00  1.7000E+0500
          0.000000    1.000000
!0 Primary Trailing Arm Bushing Lateral Stiffness00
 26   2  0.0000E+00  5.2000E+0400
          0.000000    1.000000
!00Primary Trailing Arm Bushing Lateral Damping ( 5% critical )00
 27   2  0.0000E+00  5.9000E+0100
          0.000000    1.000000
!00Radial Arm Roll Stiffness00
 28   2  0.0000E+00  8.5400E+0500
          0.000000    1.000000
!00Dummy Car Longitudinal Stiffness to Ground00
 29   2  0.0000E+00001.0000E+0300
          0.000000    1.00000000
!
!00Lat/Long Change of area stiffness00
  110      2     0.0    425.0
                 0.0      1.0
!Airbag vertical dAe/dz
  112     2   0.0    200.0
             0.0      1.0
!Airbag dummy long and lat00
  114     2   0.0      0.0
             0.0      1.0
!Airbag vertical pedestal stiffness00
  115    2   -16140   0.000
```

```
!Long/Lat dynamic shear stiffness - no stiffness
  116    2   0.0      0.0
           0.0      1.0
!Airbag vertical reservoir stiffness
  118     2   -16140  0.0
           0.0      4.356275304
!Orifice damping assuming a 15mm diameter
  119  12   0   17.88501852     71.54007409     160.9651667     286.1602964
       643.8606668     1144.641185     1788.501852     3505.46363
       7154.007409     16096.51667     28616.02964
           0   0.196850394     0.393700787     0.590551181     0.787401575
       1.181102362     1.57480315      1.968503937     2.755905512
       3.937007874     5.905511811     7.874015748
! Very stiff connection of airbag to bolster. long and lat
  155   2   0.0   1e6
            0.0   1.0
  156   2   0.0   1e3
            0.0   1.0
!Long & lat dynamic airbag connection
  160   2   0.0  1000.0
            0.0   1.0
  161   2   0.0  500.0
            0.0   1.0
!Secondary Lateral Damper
  162   2   0.0  50
            0.0   1.0
!Secondary Vertical Damper
  163   2   0.0  25
            0.0   1.0
!Anti-Roll Bar
  164   2   0.0   3e7
            0.0   1.0
```

Abbreviations and Acronyms

ACRONYMS	EXPLANATION
ATOR	Above Top of Rail
APTA	American Public Transportation Association
AREMA	American Railway Engineering and Maintenance-of-Way Association
AAR	Association of American Railroads
CFR	Code of Federal Regulations
CAF	Construcciones y Auxiliar de Ferrocarriles
DMU	Diesel Multiple Unit
EMU	Electric Multiple Unit
HS-APS	High-Speed Adjustable Perturbation Slab
IWS	Instrumented Wheelset
ISO	International Organization for Standardization
L/V	Lateral-to-Vertical
LPF	Low Pass Filter
MSRP	Manual of Standards and Recommended Practices
MTVV	Maximum Transient Vibration Value
msec	Milliseconds
MCAT	Minimally Compliant Analytic Track
PTT	Precision Test Track
PRIIA	Passenger Rail Investment and Improvement Act
RTT	Railroad Test Track
RMS	Root-Mean-Square
tare	Trainset Weight
TTC	Transportation Technology Center
TTCI	Transportation Technology Center, Inc.
WRM	Wheel-Rail Mechanism