

Chapter 2

Background

This chapter provides the results of a literature search for past studies related to this work. It further includes an introduction to track geometry and NUCARS modeling.

2.1 Literature Search

An extensive literature search was conducted to identify and review past studies in the area of railroad track irregularities. The databases INSPEC™, a leading source for literature for physics, electronics, and engineering research and Compendex, another source for literature for all engineering disciplines, were used for this search. Although these databases may not be all-inclusive, they include the vast majority of the literature studies.

This literature search resulted in a large number of articles in general areas such as “rail model,” “track model,” and “irregularity model.” The number of articles, however, did reduce considerably for narrower search topics, as shown in Fig. 2.1. We found no articles that directly addressed the issue of including track irregularities in a dynamic model such as NUCARS. A summary of some of our literature search areas is provided next.

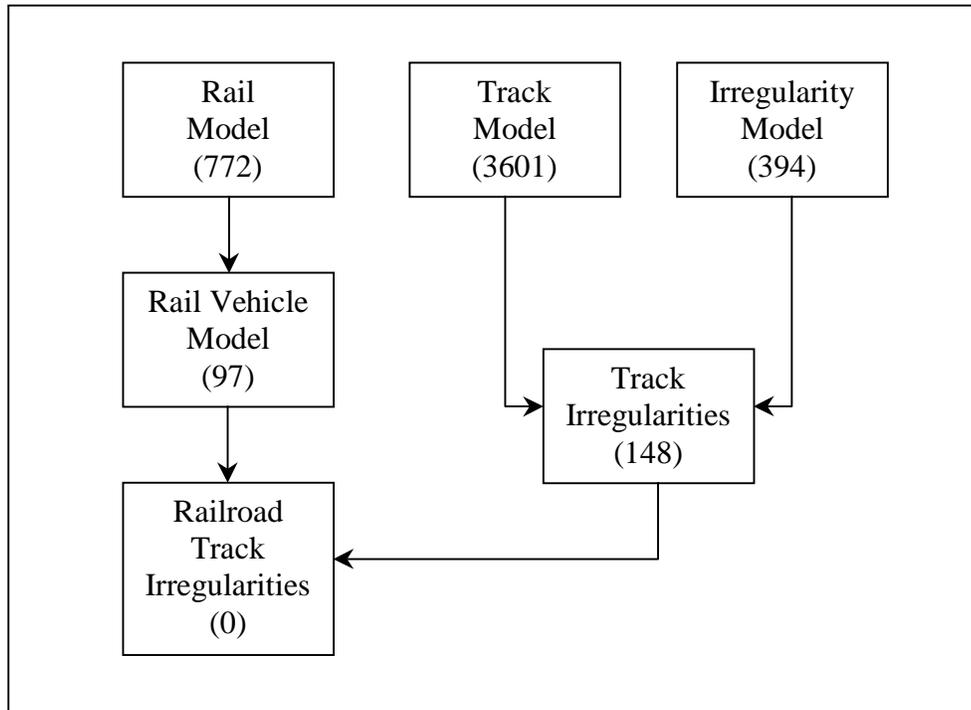


Figure 2.1 Literature Search Flow Chart; Parentheses Indicate the Number of “Hits”

2.1.1 Track Irregularities

Although there are a large number of articles in the area of track irregularities, very few relate to this study [2-6]. The studies by Naprstek and Fryba [2] and Zhai et al. [3] provide methods for modeling the track and its substructure. Naprstek and Fryba model the track and its substructure as an infinitely long beam resting on Winkler foundation, with the track surface possessing random irregularities. The dynamic behavior of the track is then modeled by subjecting the track to a moving lumped mass. The study by Zhai et al. deals with modeling the dynamics of the vehicle/track interactions and coupling the vertical and lateral interactions. The model considers the vehicle and the track as a whole system, and models the track as infinite Euler beams on elastic point supporting foundation. Equations of motion are given for the vertical, lateral, and torsional motion of the rail, as well as the other parts of the track subsystem.

A study by Zhang and Knothe [4] presents a statistical procedure for investigating vehicle curving behavior with random track irregularities. The method involves extending

the statistical linearization method on straight tracks to curved tracks. It presents a procedure for statistical linearization of the nonlinear contact geometry and nonlinear contact mechanics during curving with random track irregularities. The curving performance of rail vehicles is generally judged by using statistical methods to evaluate the measured wheel/rail interaction forces. This study also presents a method for numerically modeling curving behavior for vehicle design and performance optimization using statistical methods.

In another study, Fries and Coffey [5] review a process for generating random vertical and cross level irregularities. The method generates a time sequence to be used in a numerical simulation. The method begins with mathematical models of vertical and cross level power spectral densities (PSDs). State-space models of shape filters with frequency responses whose squared magnitudes matched the desired PSDs were then used. When driven by white noise inputs, the space filters give time histories with proper spectral contents. The first and second derivatives of the signals are also generated.

Finally, a study by Iyengar and Jaiswal [6] presents a method for modeling vertical profile irregularities as a stationary Gaussian random field. This random field can then be defined in terms of the power spectral density function. The study also shows that the absolute vertical profile of the left and right rails belongs to the isotropic random field, where the two-dimensional spectral density function is symmetrical.

2.1.2 Rail Vehicle Model

Of the many articles found addressing the rail vehicle model, only one related to this study. The study by Yoshimura et al. [7] describes an active suspension model for rail/vehicle systems based on preview and stochastic optimal control. The vehicle is modeled as a linear system with three degrees of freedom subjected to irregular disturbances. The dynamic behaviors of the irregular rail inputs are described by first-order systems with Gaussian random inputs. The study then goes on to present the equations of motion for the rail and vehicle system, and describe the rail inputs using mean-zeroed, non-stationary Gaussian random functions.

2.2 Track Geometry

The term “track geometry” refers to the various parameters that describe the layout and path of the track. Before these parameters are defined, it may be helpful if the sign conventions are first discussed. NUCARS describes the motion of each body relative to a local, track-based inertial coordinate system, shown in Fig. 2.2. The origin of the reference frame coincides with the center of gravity of the undisplaced body. The longitudinal axis, or x-axis, is parallel to the track centerline, with positive displacements in the direction of travel. The lateral axis, or y-axis, is perpendicular to the track centerline and points to the left. The vertical axis, or z-axis, points upward, to complete the coordinate system [8]. The displacements or deviations described next will follow the coordinate system shown in Fig. 2.2.

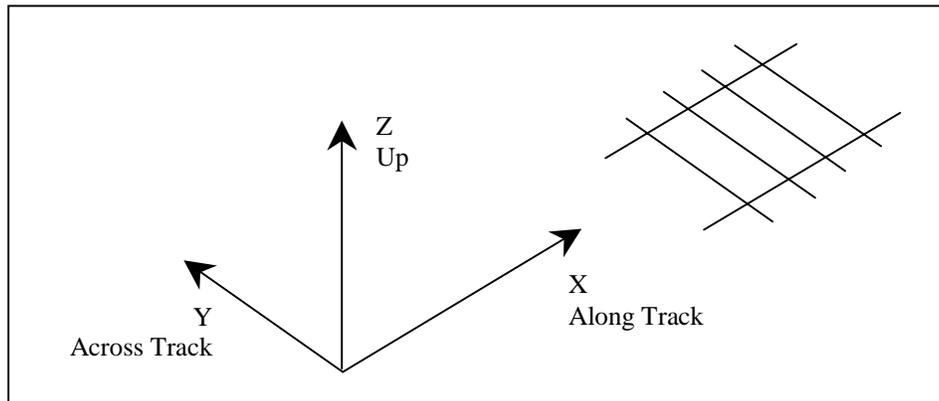


Figure 2.2 NUCARS Coordinate System [8]

There are three major types of tracks: tangents, curves, and spirals. As shown in Fig. 2.3, the term “tangent track” refers to straight track, and “curves” refers to a track with measurable curvature. The term “spirals” refers to the section of the track that provides the smooth transition between tangents and curves.

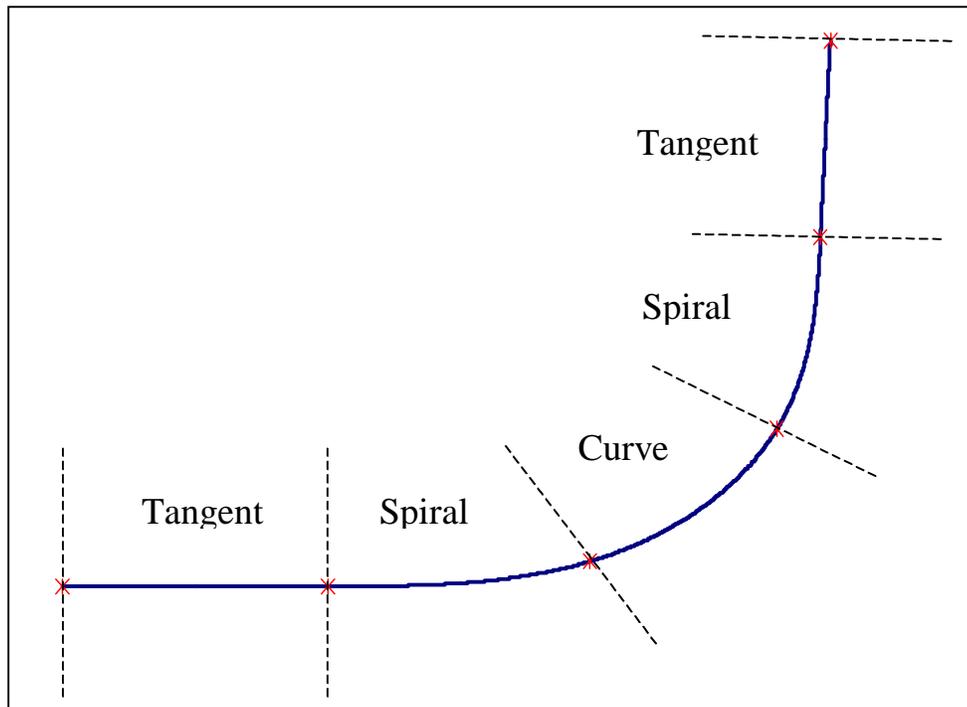


Figure 2.3 Schematic of Various Types of Track

Track curves are typically identified by degrees. As shown in Fig. 2.4, a one-degree curve is defined as a curved section of the track with a radius such that a 100-ft cord corresponds to a one-degree arc [9].

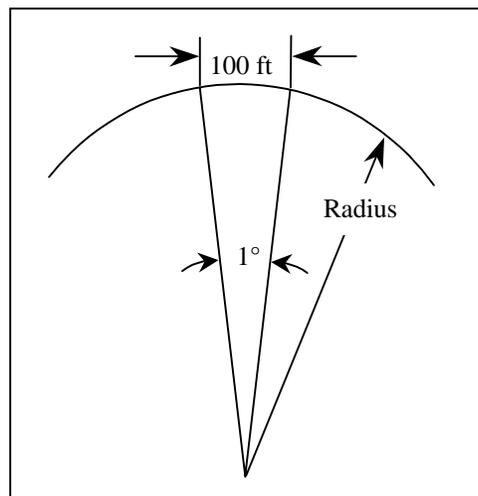


Figure 2.4 Track Curvature [9]

According to the above definition, one can determine the mathematical relationship between the degree of curvature and the radius of the curve as

$$\text{deg ree_of_curve} = \frac{5730}{\text{curve_radius(ft)}} \quad (2.1)$$

To compensate for the centrifugal forces that the vehicle will experience when traveling through a curve, the outer rail may be raised, or super-elevated, to tip the cars inward. The amount of elevation that the outer rail in a curve is raised above the inner rail is called the “superelevation.” When the left rail is raised above the right rail, it results in a positive superelevation, and a negative superelevation refers to a situation when the right rail is raised above the left rail.

2.3 Track Irregularities

Railroad tracks are placed along a nominal centerline or path. This nominal centerline is the ideal, or intended, path of the track. No track is laid perfectly, so there will always be small deviations from this ideal path. The deviations that occur laterally are described by the alignment and gauge, and the vertical deviations are described by the profile and cross level.

2.3.1 Alignment

The alignment is defined as the lateral deviation of the midpoint of the two rails from the nominal centerline of the track, shown in Fig. 2.5. It should be noted that the sizes of the deviations shown in Fig. 2.5, and the subsequent figures, are for illustration purposes only and are not representative of actual track deviations. Given the sign conventions discussed earlier, a positive deviation in the alignment denotes a lateral deviation of the track to the left, while a negative deviation in the alignment represents a lateral deviation of the track to the right.

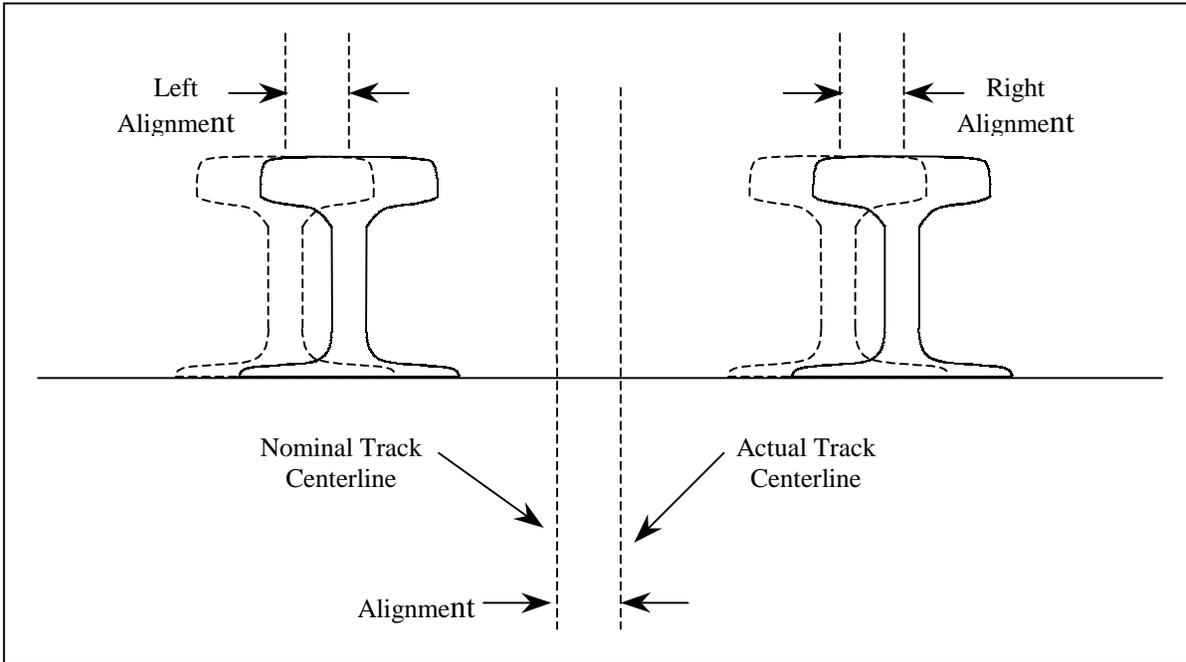


Figure 2.5 Illustration of Track Alignment Deviation

2.3.2 Gauge

The gauge can be described in two ways. First, gauge can be defined as the lateral deviation of the width or distance between the rails. Gauge can also be defined as the lateral deviation of the track from its nominal gauge, which is 56.5 inches (1435 mm) on the U.S. main lines, as shown in Fig. 2.6. NUCARS and TRAKVU use the latter of the two definitions.

Therefore, the term gauge, when discussing track geometry, will refer to the deviation of the track from its nominal gauge. A widening of the gauge corresponds to a positive deviation, while a negative deviation corresponds to a narrowing of the gauge.

The left alignment and right alignment are the lateral deviations of each rail from its nominal path. They can be calculated from the alignment and gauge according to

$$\text{Left_Alignment} = \text{Alignment} + \frac{\text{Gauge}}{2} \quad (2.2)$$

$$\text{Right_Alignment} = \text{Alignment} - \frac{\text{Gauge}}{2} \quad (2.3)$$

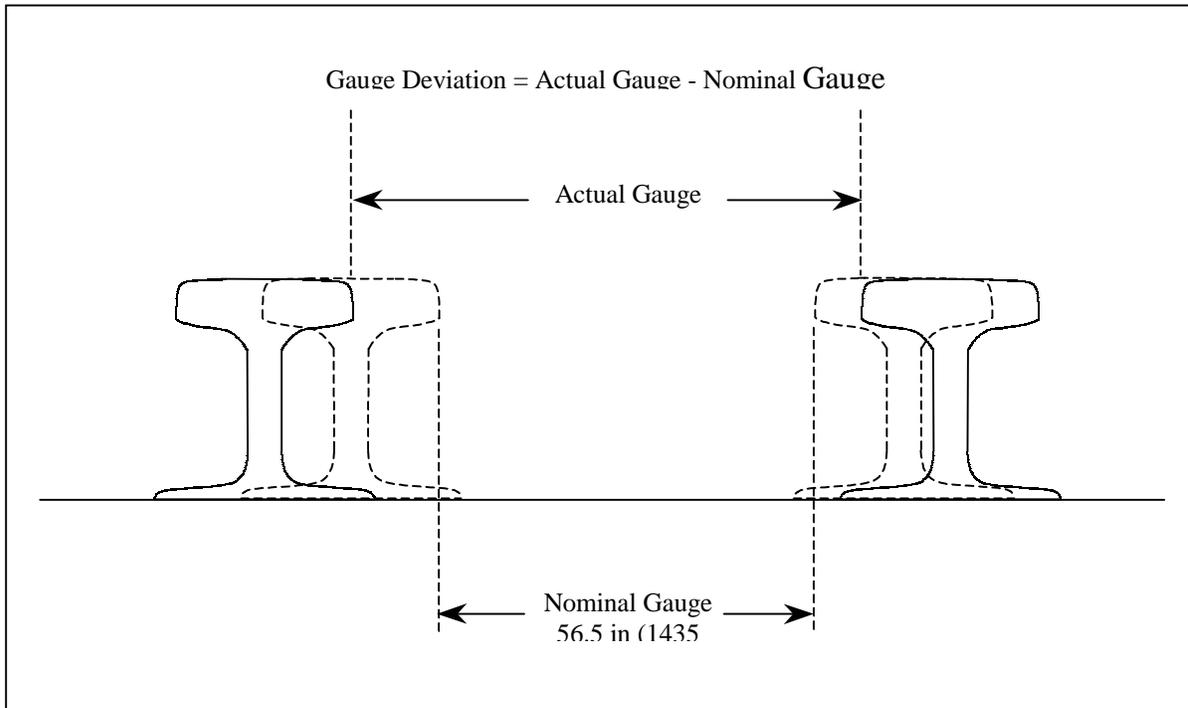


Figure 2.6 Illustration of Track Gauge Deviation

Conversely, if the data are provided as left and right alignments, the alignment and gauge can be calculated using

$$\text{Alignment} = \frac{\text{Left_Alignment} + \text{Right_Alignment}}{2} \quad (2.4)$$

$$\text{Gauge} = \text{Left_Alignment} - \text{Right_Alignment} \quad (2.5)$$

As Eqs. (2.4) and (2.5) indicate, the track irregularities associated with the alignment and gauge are also included in the left and right alignments.

2.3.3 Profile

Profile is defined as the vertical deviation of the midpoint of the two rails from the track's nominal elevation, as shown in Fig. 2.7. Using the correct sign conventions, a positive

deviation in profile refers to an upward vertical deviation of the track, and a negative deviation in profile represents a downward vertical deviation of the track.

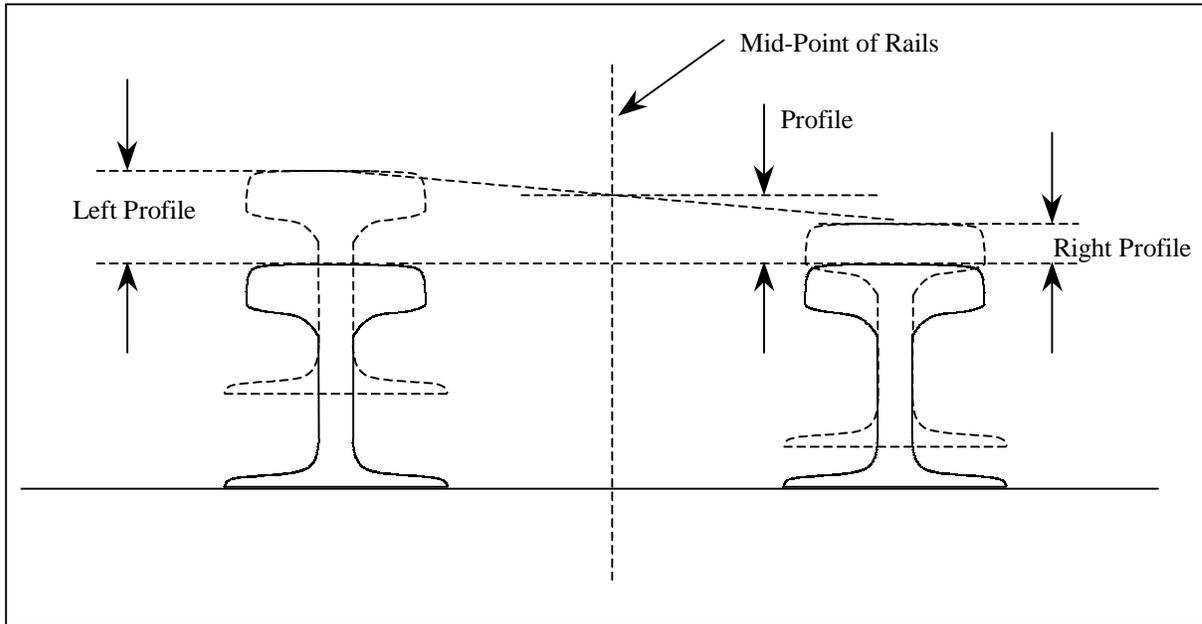


Figure 2.7 Illustration of Track Profile Deviation

2.3.4 Cross Level

The cross level, not to be confused with the superelevation, is the amount of vertical deviation between the left and right rail from their intended distance, as illustrated in Fig. 2.8. The intended distance refers to the amount of superelevation. For instance, if the superelevation is zero, then any difference between the elevation of the left and right rail is the cross level. If the superelevation, however, is a positive three inches (7.62 cm), for example, then the cross level is the deviation from this superelevation. A positive cross level refers to the case when the left rail is above the right rail, and a negative cross level refers to an instance when the left rail is below the right rail.

The left profile and right profile are the vertical deviations of each rail from its nominal path and can be calculated from the profile and cross level using Eqs. (2.6) and (2.7).

$$\text{Left_Pr ofile} = \text{Pr ofile} + \frac{\text{Cross_Level}}{2} \quad (2.6)$$

$$\text{Right_Pr ofile} = \text{Pr ofile} - \frac{\text{Cross_Level}}{2} \quad (2.7)$$

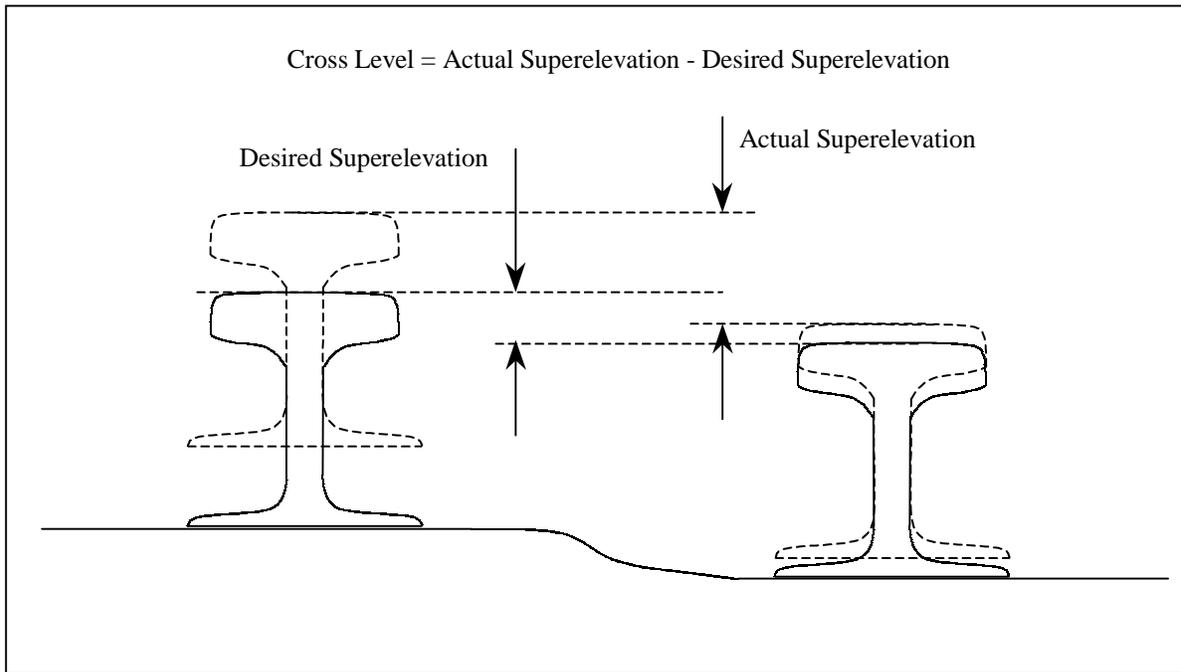


Figure 2.8 Illustration of Track Cross Level Deviation

Conversely, if the data are provided as left and right profiles, the profile and cross level can be calculated using Eqs (2.8) and (2.9).

$$\text{Pr ofile} = \frac{\text{Left_Pr ofile} + \text{Right_Pr ofile}}{2} \quad (2.8)$$

$$\text{Cross_Level} = \text{Left_Pr ofile} - \text{Right_Pr ofile} \quad (2.9)$$

From these equations, it can be seen that the track irregularities associated with the profile and cross level will also be included in the left and right profile, as with the alignment data.

2.4 Track Class

The term “track class” refers to the Federal Railroad Administration (FRA) track class designations. The classes range from 1 to 6, with track class 1 designating the worst track and class 6 identifying the best track. Track classes are determined by the deviations from the ideal track (i.e., a track with nominal parameters), and they are used to regulate the safe operating speed for different types of traffic as shown in Table 2.1.

Table 2.1 Track Class Speed Limits

Track Class	Speed Limit	
	Passenger	Freight
1	15 MPH (24 km/hr)	10 MPH (16 km/hr)
2	30 MPH (48 km/hr)	25 MPH (40 km/hr)
3	60 MPH (97 km/hr)	40 MPH (64 km/hr)
4	80 MPH (129 km/hr)	60 MPH (97 km/hr)
5	90 MPH (145 km/hr)	80 MPH (129 km/hr)
6	110 MPH (177 km/hr)	110 MPH (177 km/hr)

2.5 NUCARS Modeling

New and Untried Car Analytic Regime Simulation (NUCARS) is a time-based program that can be used for various dynamic analyses. The program was developed and is supported by TTCI. NUCARS dates back to the mid-1980s, when a group of researchers at the Massachusetts Institute of Technology (MIT) decided to prepare a simulation tool for dynamic analysis of rolling stock. Since then, it has evolved into an industry-standard

dynamic analysis tool that is widely used by the railroads for such applications as derailment and rail rollover.

A NUCARS model includes five separate files that are used to describe the dynamic system, the input, and the output parameters. The files required are the SYS file, the INP file, the DAT file, the WRG file, and the RUN file. What follows is a brief description of each file and its purpose within the NUCARS model.

The SYS file includes the dynamic system and is the most important part of the NUCARS model. The system is represented as a collection of lumped bodies, connected together by a series of connections, as shown in Fig. 2.9.

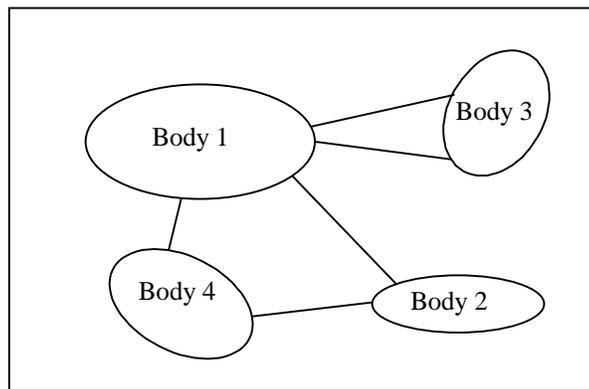


Figure 2.9 System of Interconnected Bodies [1]

Each body is identified by the location of its center of gravity (CG), inertial properties, and the degrees of freedom it holds. The inertial properties include the mass and moments of inertia about a spatial local coordinate system located at the CG. Each body can have multiple connections with other bodies. These connections are identified by their location and properties. The location of each connection is the set of coordinates of its effective center (commonly the center of connection) or connection ends in the global coordinates. Each connection is defined by a resilient and dissipative element that is configured properly to represent the physical connections between the bodies. NUCARS provides connections with different properties that can model both linear and nonlinear properties of the connecting elements commonly used in rail vehicles [1].

The INP file represents the system input during the simulation run. The input can be specified either through input history data or according to track geometry data. Track geometry data can be either measured data or analytically created data as discussed earlier in Section 1.2. Track geometry data can be modeled in NUCARS in various forms. It can be presented as a perturbed track input, either by mathematical shapes internal to NUCARS or by external files. In this case, the mathematical shapes are generated by NUCARS, and therefore will not contain the irregularities associated with actual track. The track curvature and superelevation are supplied in a piecewise linear form for these options. The external files contain measured track binary data for all of the track geometry parameters.

The DAT file defines the data output by the model. For each body, the output can include the displacement, velocity, acceleration, and net force at the CG. All connections information, such as the stroke, velocity, and forces, can be output as well. Other measures, such as wheel/rail wear index and rail wear index, wheel/rail contact forces, and the ratios of lateral and vertical forces, are possible.

The WRG file is an array of numbers that describes the non-linear wheel/rail contact condition and is used to determine creep forces. The WRG file is created from empirical data for different combinations of wheel profiles and rail weights. AAR provides these files as part of the NUCARS package, and in most cases, there is no need to alter them.

The RUN file is a collection of the information needed to run a NUCARS simulation. It includes the name and disk location of all the files necessary to run NUCARS. It further includes information about the vehicle forward speed, the coefficients of friction between the wheel and rail, the calculation time step size, the output interval, and an optional output low-pass filter [1].

NUCARS has many other features that fall outside the scope of this study. A detailed write-up of all NUCARS features can be found in the NUCARS manual [8].