

The work described in this document was performed by Transportation Technology Center, Inc.,  
a wholly owned subsidiary of the Association of American Railroads.

## **A Multibody Dynamics Approach to the Modeling of the Three-Piece Truck for Freight Train Suspension**

Corina Sandu, Jennifer Steets, Brent Ballew, Brendan Chan  
Railway Technologies Laboratory, College of Engineering, Virginia Tech  
Nicholas Wilson and Curtis Urban, TTCI

### **Summary**

Through the Association of American Railroads' (AAR) Strategic Research Initiatives (SRI) Technology Scanning Program, researchers at Virginia Tech (VT) and the Transportation Technology Center, Inc. (TTCI) have developed an improved model of freight car truck suspensions. This model will allow better analysis and more rapid development of improved designs. Improved vehicle performance and the performance of the three-piece freight car truck are key elements of the railroads' goals of improving safety, efficiency, network reliability, and capacity.

A multibody dynamics approach has been employed to capture the complex frictional contact for the friction wedge interaction with the bolster and the side frame, which is critical in quantifying the wedge behavior during lift-off and the stick-slip phenomena that can occur in typical operating conditions. This study has produced a stand-alone model that will better characterize the interaction between the bolster, the wedge, and the side frame. The new model allows the wedge four degrees of freedom: vertical and longitudinal displacements (between the bolster and the side frame), pitch (rotation about the lateral axis), and yaw (rotation about the vertical axis). It also allows for toe in and toe out of the friction wear surfaces. The resulting friction wedge model is a 3D, dynamic, stand-alone model of a bolster-friction wedge-side frame assembly, capable of capturing dynamics of the wedge otherwise not possible to simulate. The dedicated train modeling software NUCARS<sup>®</sup> has been used to run simulations with similar inputs and to compare the results with those obtained from the new stand-alone friction wedge model. The stand-alone model shows improvement in capturing the transient dynamics of the wedge better and can predict normal forces and moments transmitted between the side frame and bolster.

The study has been further extended to a half-truck model, comprised of four rigid bodies: a bolster, two friction wedges, and a side frame assembly. The model allows each wedge four degrees of freedom, as in the previous model. The bolster and the side frame have only the vertical degree of freedom. The geometry of these bodies can be adjusted for various simulation scenarios. The bolster can be initialized with a predefined yaw displacement and the side frame may be initialized with predefined pitch displacements and friction wear surface toe angles. The stand-alone half-truck model simulation results have been compared with results from NUCARS.

The Railway Technologies Laboratory at VT is an Affiliated Laboratory under the AAR Technology Scanning SRI. Missions of the Technology Scanning Program are to exploit new technologies and to provide technical experts for the railroad industry.

\*Nucars<sup>®</sup> is a registered trademark of the Transportation Technology Center, Inc. USA



**INTRODUCTION**

The three major components of a three-piece truck are two side frames and a bolster. The side frames run parallel to the track and are connected to each other by a bolster, running transversely to the track. The side frames are supported by the wheelsets through the primary suspension, which includes the bearing adapter and pedestal. The secondary suspension connects the bolster to the two side frames, and includes the load coils and the friction wedges, which are the main source of damping. Moreover, the friction wedge provides some resistance to yaw motions (warp resistance) between the bolster and side frames. Because of the wedge’s nonlinear frictional characteristics and load sensitive behavior, accurately capturing its dynamics in a computational model proves difficult.

Despite their apparent simplicity, three-piece truck suspensions are complex and difficult to model accurately. In particular, the friction wedge performs dual functions of providing the main source of damping and also holding the sideframes square to the bolster. The wedges have almost negligible mass compared to the other components, and therefore have not usually been treated as a body, but as a simplistic force element. The inertial properties of the wedges have been ignored and their motions and friction forces have been represented through a system of equations. For this new study, the wedge is considered as a rigid body, for which the full kinematics and dynamics analysis can be performed.

**Research Approach**

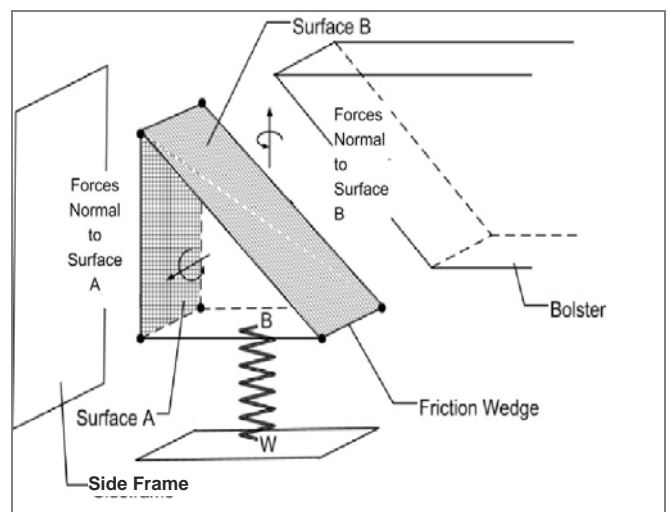
A stand-alone quarter-truck model was developed in MATLAB®. As Figure 1 shows, the model includes the mass and inertia for both friction wedges and the bolster. VT has assumed reaction forces are generated at the contact interface between surface A and the side frame and surface B and the bolster. The friction damping behavior is modeled as tangential forces that depend explicitly on the coefficient of friction ( $\mu$ ) and the normal force.

The moments generated as a result of the friction couple excite the rotational degrees of freedom of the wedges. The four degrees of freedom of the stand-alone wedge model are the yaw and pitch rotations, and the vertical and longitudinal translations. Assumptions made in the design of the stand-alone friction wedge model were:

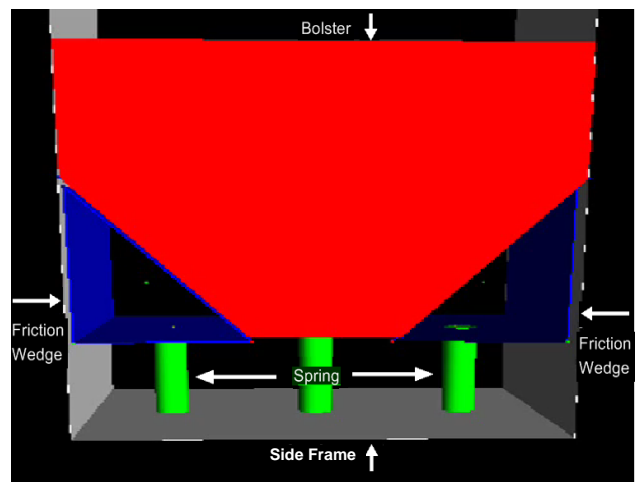
- The wedge may not be in contact with the bolster or the side frame at all times.
- A small amount of shear displacement occurs at the interface surfaces before slip occurs.
- Points on the edges of the wedge surface are used to define the geometry of the wedge.
- The side frame and the bolster forces are modeled as compliant reaction forces, resulting from unilateral contact springs acting normal to the contact surface, which only appear when the wedge comes into contact with the side frame and/or the bolster.
- The control coil springs are modeled as linear springs.

- Surfaces A and B are considered flat (in reality they are slightly curved).
- In order to provide equivalent quantitative comparison between the MATLAB stand-alone model and existing NUCARS® models, bolster displacement inputs were used, resulting in the motion of the wedge.

To correctly simulate pitching and yawing motions, a half-truck model, illustrated in Figure 2, was created to include a side frame, bolster, two friction wedges, the springs supporting the bolster (the load coil), and the friction wedges (control coils). The half-truck model is based on similar modeling assumptions as the quarter-truck model, but this time the side frame was used as the input body. Also, the bolster was modeled as a body with mass and inertial properties.



**Figure 1. Exploded View of the Side-Frame Friction**



**Figure 2. New Variably Damped Half-Truck Model Wedge-Bolster System for the Variably Damped Wedge Model**

**Quarter-Truck Model Results**

Figure 3 shows that the vertical wedge force results from the stand-alone model (in toe out configuration, with sideframe friction wear plates slightly farther apart at the bottom than at

the top) compares well to results obtained with NUCARS using both the Type 6.8 (a two-dimensional wedge connection with stick-slip capabilities) and the Type 6.9 (three-dimensional wedge connection) elements. As depicted, Section (1) represents the force due to the bolster moving down vertically, pressing against the wedge, and forcing it to slip down the face of the side frame. Section (2) represents the stick phase of the motion when the wedge face friction force and the direction of the motion relative to the side frame changes from sliding down to sliding up. Section (3) is the result of the wedge and bolsters moving upwards. In Section (4), the bolster is lifted off of the wedge completely and the wedge force oscillates around 0 pounds. One goal of the current work was to minimize the noise seen in the output of the stand-alone model in Section (1).

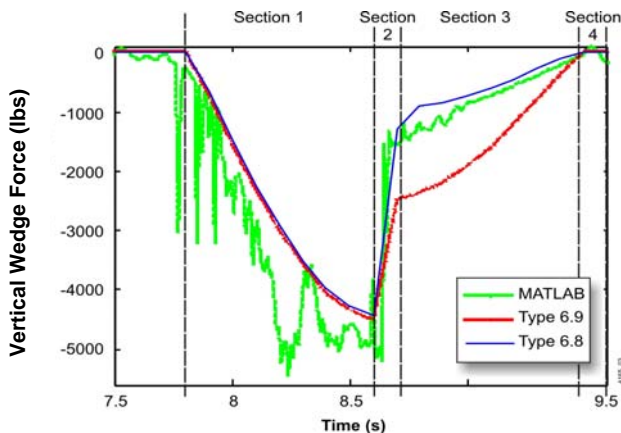


Figure 3. Vertical Wedge force in NUCARS® and in the Stand-alone Model with Toe Out with a Static Bolster Yaw Displacement

Figure 4 compares the hysteresis loops of vertical wedge forces shown in Figure 3 to the vertical wedge displacements for both of the NUCARS models and the stand-alone model.

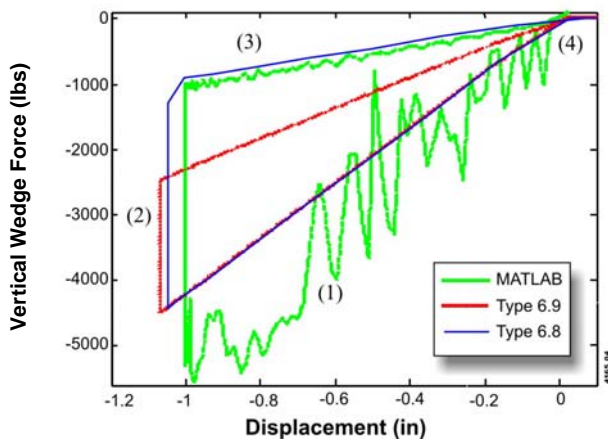


Figure 4. Vertical Wedge Force Hysteresis Loops in NUCARS and in the Stand-alone Model with Toe Out with a Static Bolster Yaw Displacement

Figures 5 and 6 compare time histories and hysteresis loops for the toe in, toe out, and no toe geometries of the stand-alone model for a vertical displacement and static bolster yaw rotation as inputs. The differences between the toe out (0.02

radian), toe in (-0.02 radian), and no toe (0 radian) versions can be attributed to the geometry of the bolster-wedge-side frame system, which changes with toe angle.

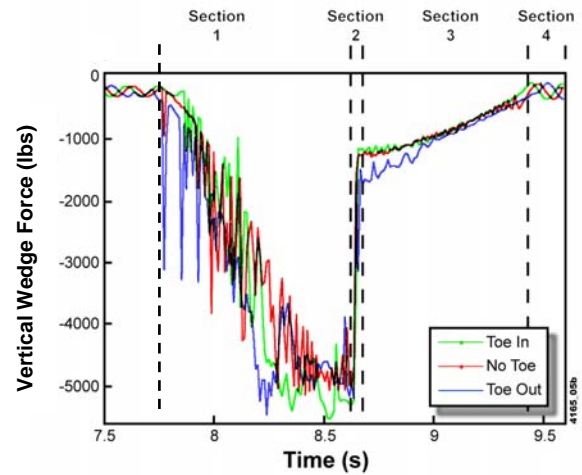


Figure 5. Vertical Wedge Force in the Stand-alone Model for Three Toe Cases with a Static Bolster Yaw Displacement

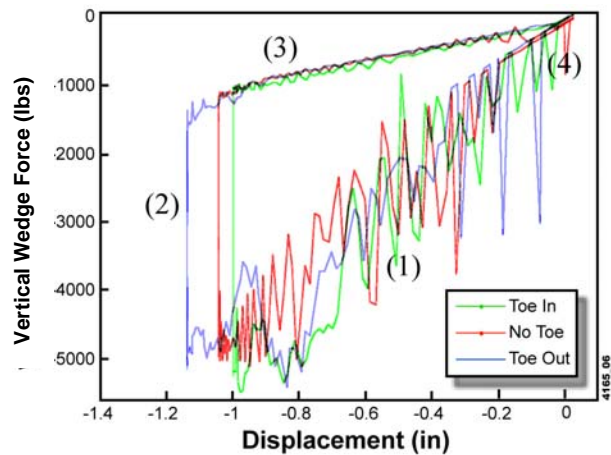


Figure 6. Vertical Wedge Force Hysteresis Loops in the Stand-alone Model for Three Toe Cases Out with a Static Bolster Yaw Displacement

### Half-Truck Simulation Results

The half-truck simulations were conducted with a 0.77 Hz and 1-inch vertical displacement input to the side frame. This input frequency was used in the simulations to induce lift-off (bolster-wedge separation) and permits easier analysis and identification of the periodic nature of the output.

Figure 7 compares the 0.034 radian (2 degrees) toe out, 0.034 radian (-2 degrees) toe in, and (0 degree) no toe configurations of the stand-alone half-truck model. As expected, the toe-out forces are smaller than those for the toe-in configurations. The higher vertical forces for toe-in is due to the side frame and wedge interaction geometry causing the wedge to jam or lock up. The direction of the friction forces on the wedge sides for the toe-in case leads to a greater tendency for wedge lock up than for the zero toe and toe-out configurations.

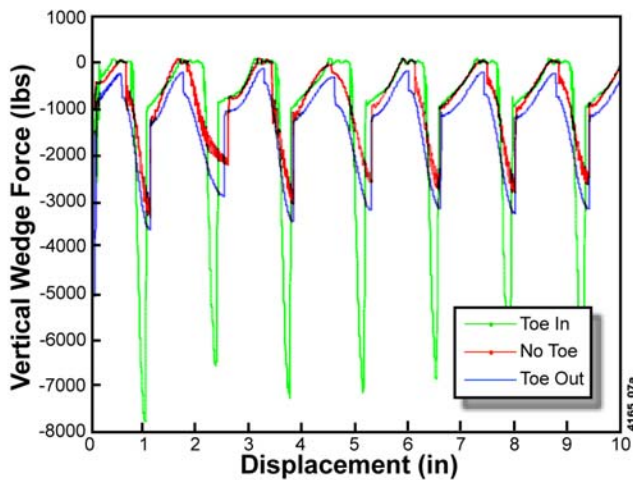


Figure 7. Vertical Forces for Three Toe Conditions

Figure 8 shows the rate of energy dissipated by the side frame-wedge surface for the three-toe configurations. As for the quarter-truck model, the half-truck stand-alone model has the capability to calculate and output the moments acting on the wedge as well as the forces. Figure 9 shows that the wedge lockup also generates large pitch moments. With no bolster yaw angle, the roll and yaw moments are negligible.

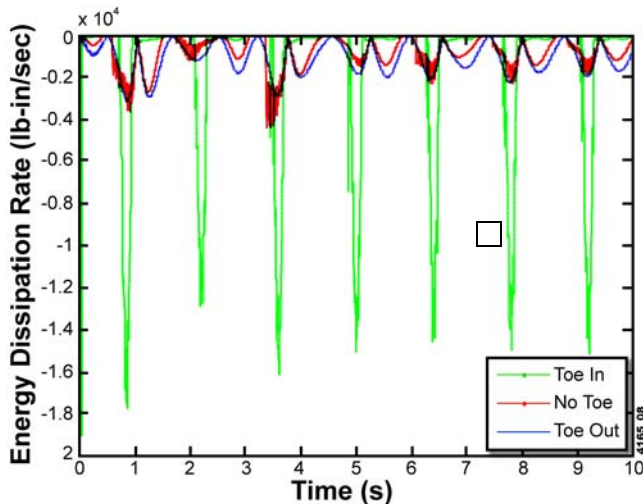


Figure 8. Energy Dissipated due to Side Frame Friction Wedge Contact

**CONCLUDING REMARKS**

VT has developed stand-alone models to study the bolster-friction wedge-side frame dynamic interaction. The stand-alone half-truck model includes inertial properties of the wedges and bolster as well as two directions of translational motion (vertical and longitudinal) and two rotations (yaw and pitch). The multibody dynamics approach allows the propagation of forces and moments due to the side-frame/wedge-bolster interactions.

The development of this model provides the opportunity to investigate improvements to the overall railcar response, including critical situations such as wedge lock-up. Friction wedge models able to predict realistic forces and moments can improve railcar simulations and help prevent possible derailments.

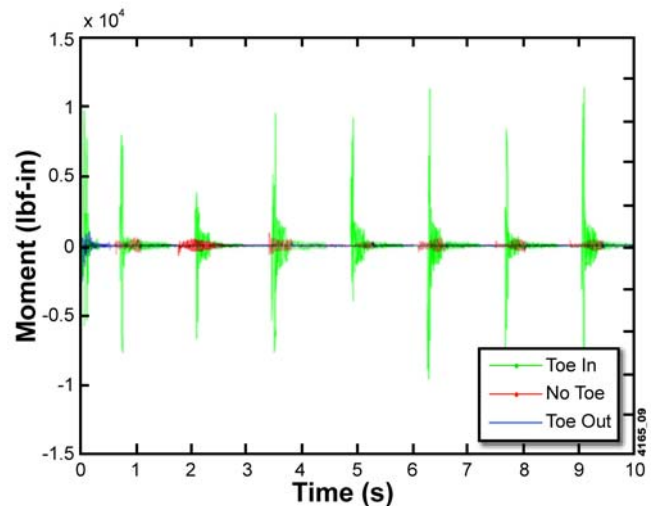


Figure 9. Pitch Moments for Three Toe Configurations

**Acknowledgements**

VT acknowledges and appreciates the support of the AAR and TTCI for supporting this project. A special thanks to Mr. Dave Davis for serving as Technical Monitor for the AAR-Affiliated Program.

**BIBLIOGRAPHY**

Cusumano, J.P. and J.F. Gardner. March 18-20, 1997. "Dynamic Models of Friction Wedge Dampers," *Proceedings of the 1997 IEEE/ASME Joint Rail Conference*. Boston, MA.

Dankowicz, H. 2004. *Multibody Mechanics and Visualization*, Springer-Verlag.

Klauser, P. E., Nov. 13-20, 2004, "Modeling Friction Wedges Part I: The State-of-the-Art," Proc. IMECE04. Anaheim, CA.

— Nov. 13-20, 2004. "Modeling Friction Wedges Part II: An Improved Model," Proc. IMECE04. Anaheim, CA.

Okamoto, Isao. Dec. 18, 1998. "How Bogies Work," *Railway Technology Today*, Japan Railway & Transport Review.

Steets, J., B. J. Chan, and C. Sandu, (Unpublished) "A Multibody Dynamics Approach to the Modeling of Friction Wedge Elements for Freight Train Suspensions. Part I: Theory," pending with the *Journal of Transportation Engineering*.

Transportation Technology Center, Inc. 2006. *NUCARS® Version 2006 Users Manual*. Pueblo, Colorado.

Visit our website at <http://www.ttc.aar.com>