

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

Key Findings:

- Introducing a more detailed coupler model to replace the simplistic representation of the solid drawbar generated results that more closely matched on-track test results.
- Preliminary modeling involving a simplified coupler arrangement, represented by a solid drawbar, showed that large wheel-rail lateral forces could be generated from large in-train buff forces.
- Results and observations from the on-track tests showed that the cars did not take up a jackknife orientation as a result of steady state buff forces approaching 300 kips, and thus no large, wheel-rail lateral forces were generated.

NUCARS[®] Evaluation: The Effects of High In-train Forces on Track Stability

Stan Gurulé, Anna M. Rakoczy, and Yin Gao

[Transportation Technology Center, Inc. \(TTCI\)](#) conducted NUCARS* simulations to help develop a plan for performing on-track tests at the Transportation Technology Center (TTC) near Pueblo, CO. The focus of this research, conducted in the summer of 2018, was on evaluating track lateral stability under high lateral wheel-rail forces.

This work is part of a larger study under the Association of American Railroads' (AAR) Strategic Research Initiatives (SRI) program to evaluate the effects of wheel-rail forces that may result from large longitudinal in-train loads. This *Technology Digest* presents the supporting pre- and post-test modeling results.

An earlier modeling study showed that large lateral loads could be predicted under the conditions of high buff load in combination with coupler angularity.^{1, 2} These same three-car vehicle models, both empty and loaded, were used again to help define a test plan and procedure for full-scale, on-track testing at TTC. Pre-test modelling was used to help identify where on the track instrumentation should be installed in addition to helping define the test run matrix for the on-track tests.

Post-test modeling was conducted by refining the models to better match the test results. The most obvious distinction between test results and pre-test modeling results was that the tests did not generate large lateral forces. They also did not show the car-to-car jackknifing phenomenon, as predicted in the preliminary modeling.

It was determined that the simplistic representation of the cars coupling arrangement was the primary reason for the discrepancy. The post-test coupler models were updated to a more sophisticated and detailed representation and the updated model produced results that more closely matched the test data results. Also, the post-test models did not show a tendency for jackknifing as a function of increased buff load.

Railroads in North America have reported increased demands on the track infrastructure as a result of longitudinal in-train forces. TTCI developed a research program to conduct simulations and tests to record dynamic load data in order to

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make reasonably accurate estimates of the effects of in-train forces and explore options for minimizing detrimental effects of these forces on track.

MODELING OVERVIEW

The modeling effort helped identify optimal locations within the target test zone to install wayside instrumentation, and also helped define the test run matrix. Two models were developed — one for each load condition. Each model was composed of three coupled cars. The models were developed under an earlier study representing both loaded and empty standard hopper cars.^{1,2} The three-car models were simulated over a range of increasing buff load on both tangent and curved track. The three-car models were coupled together using a simplistic representation for a coupler; basically, a solid drawbar arrangement was simulated. This approach was suitable at the time, as it represented a worst-case coupler condition and answered the fundamental question of whether large track lateral forces could be generated using mathematical models. The earlier study and the preliminary modeling for this effort showed that as buff load increased for the empty car models, the cars had an increasing tendency to jackknife relative to each other — which resulted in large predicted lateral loads. The loaded car simulations did not show this tendency.

Simulations were conducted using measured track geometry of the Wheel Rail Mechanisms (WRM) Loop at TTC, traversing the 4-degree curve and subsequent tangent track in the counterclockwise direction. The results were analyzed by segmenting the track into separate zones: the entry spiral to the 4-degree curve, the body of the 4-degree curve, the exit spiral of the 4-degree curve, and the tangent track beyond the 4-degree curve. Based on these preliminary results, it was decided to locate the wayside track instrumentation in the body of the curve, the exit spiral and tangent track. Additional details of the test program are described in an accompanying *Technology Digest*, TD-19-006.³

In addition, the preliminary modeling also helped to identify which truck of the three-car test consist would be the optimal for installation of the instrumented wheelsets (IWS). Based on the preliminary modeling results, the trailing truck of the middle (or second) test car was chosen as the truck for installation of the IWS (see Figure 1).

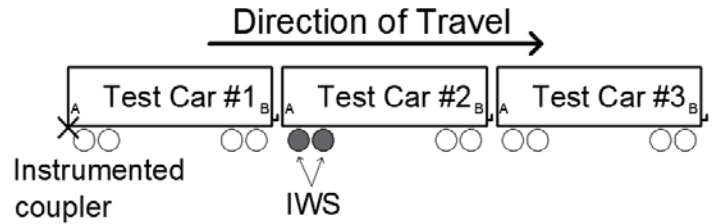


Figure 1. IWS location determined through modeling

The preliminary modeling was conducted for a range of applied buff force from 100 to 300 kips in 25-kip increments. All simulations were run with dry rail conditions with rail coefficient of friction set to 0.5. Simulations were all run at a constant low speed of 7 mph with steady state buff load at each increment.

Figure 2 shows an example of the preliminary axle lateral-to-vertical load ratio results of the empty and loaded cars with new and worn wheel and rail in the body of the 4-degree curve. The result shows the empty cars are exceeding the Prud'homme limit⁴ at 200 kips and above, and the TLV limit⁵ at 225 kips and above, while the loaded cars do not show an increasing trend of axle load ratio as a function of increasing buff force. The dramatic jump in the axle load ratio for the empty car is due to the NUCARS model predicting the cars jackknifing under high buff force, resulting in increased predicted lateral forces. This phenomenon was not seen during the on-track tests.

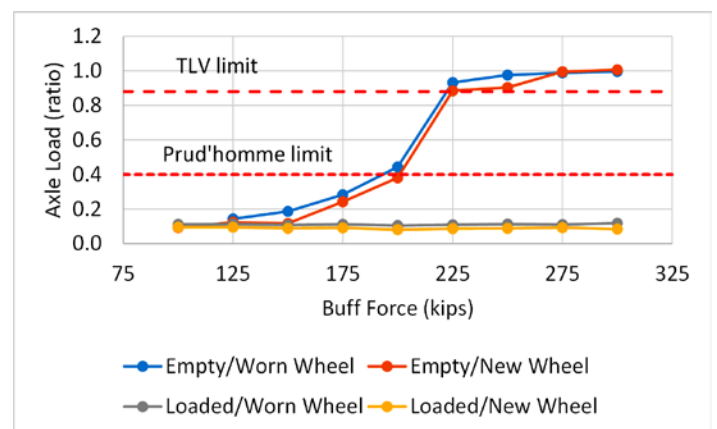


Figure 2. Preliminary modeling results of axle load ratio, 4-degree curve

POST-TEST MODEL MODIFICATION

The most notable result from the on-track tests was that the cars did not jackknife under high buff load; neither empty nor loaded. A review of the coupler displacement measurements from the test data revealed that the couplers did not swing

much relative to their respective carbodies, nor to each other. Whereas, the simplified coupler (drawbar) models took up large angularity at higher buff loads to the limits of their physical stops. Consequently, a more detailed coupler model was introduced. Each coupler body was defined separately connected to its respective carbody along with a connection between each coupler, as opposed to a simple drawbar connecting adjacent cars. Figure 4 shows a 3D illustration of the coupler-to-coupler model defined in NUCARS. The couplers were modeled as separate bodies, each connected to their respective cars by defining: 1) draft gear force control with a surface friction element; 2) draft gear compression using a shearing element to simulate over-center pivot action of forces on the coupler butt; 3) lateral and vertical supports at the coupler pivot with yaw and pitch degrees-of-freedom; 4) striker stops for both vertical and lateral direction; and 5) coupler-to-coupler joint with friction in the vertical direction.

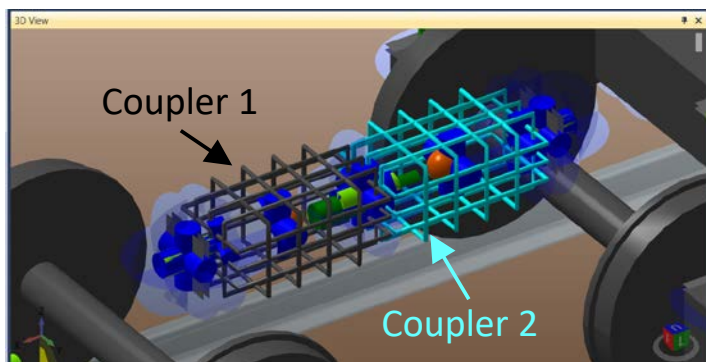


Figure 3. NUCARS® 3D coupler-to-coupler model

This car-to-coupler-to-coupler-to-car model performed much more like what was observed in test. The performance of this model essentially showed that as buff force was increased, as opposed to assuming a large angularity, or jackknifing, the couplers tended to square themselves to the carbody. This resulted in post-test modeling results that more closely matched the on-track test results — most notable, the predicted performance no longer showed the jackknifing phenomena.

In addition to improving the coupler models, the preliminary car models also were updated to match the actual weight of the test cars, as well as utilizing the measured wheel profiles from each of the test cars.

Figure 4 shows an example of a comparison of the NUCARS results with the simplified coupler model (NUCARS drawbar) versus the more sophisticated coupler model (NUCARS

coupler). The result shows the dramatic difference of the predicted performance as a consequence of updating the model. Again, this difference is due to the fact that by improving the coupler model, the cars no longer showed a tendency to jackknife under high buff forces.

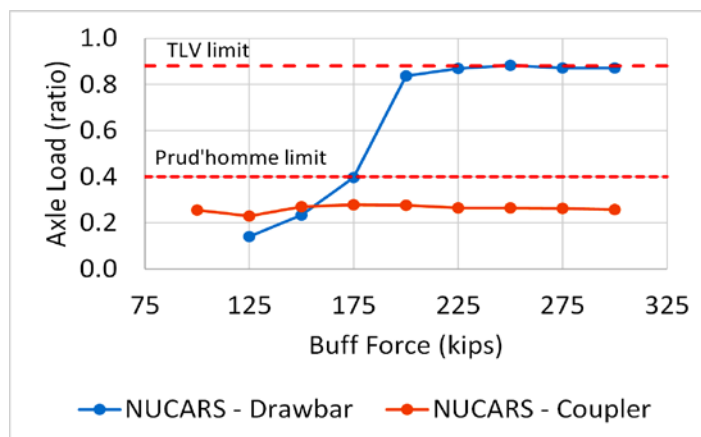


Figure 4. Comparison of drawbar vs. coupler axle load ratio for empty car results

POST-TEST MODEL VALIDATION

Figure 5 shows the comparative results of axle load ratio for the empty cars between NUCARS model versus test. The figure shows the comparative results for the 4-degree exit spiral test zone.

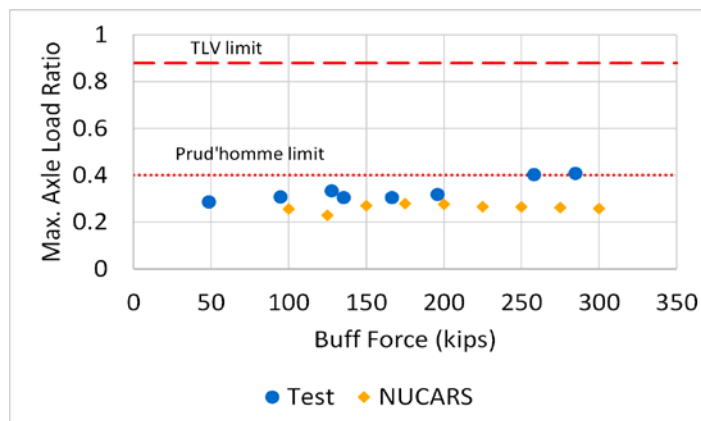


Figure 5. Model vs. test results of axle load ratio for the empty cars in 4-degree exit spiral test zone

In general, the predicted results from modeling are slightly lower and show a flatter trend than the test results, but clearly no longer show the dramatic jump shown in Figure 4 caused by the cars jackknifing. Some of the differences between the model and test results may be due to initial conditions or positions of the couplers not exactly matching those in the

model. Also, there is uncertainty of the condition of the couplers in terms of wear. Generic coupler characteristics were used in defining the coupler connections and may not be of the exact coupler type present in the test cars. Characterizing and replicating the exact couplers present in each of the test vehicles was beyond the scope of this modeling effort.

Figure 6 shows the similar comparative results of axle load ratio for the loaded cars between the NUCARS model and testing. The figure shows the comparative results for the 4-degree exit spiral test zone. The comparative results are much closer than the empty car results. None of the simulation results show any exceedance of the various criteria while the test results were just at the Prud'homme limit at the two highest buff force loads

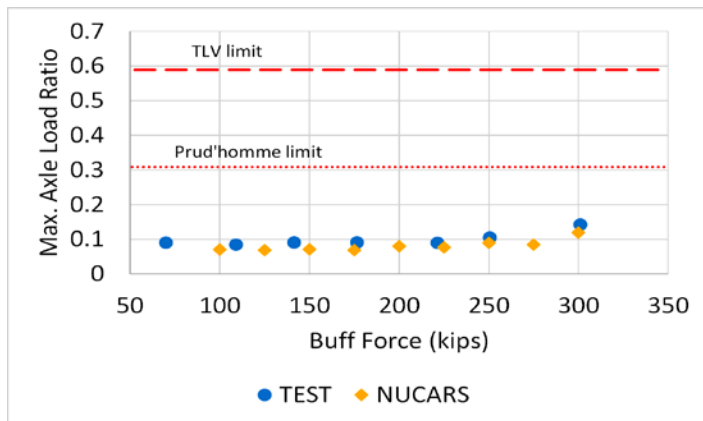


Figure 6. Model versus test results of axle load ratio for the loaded cars in the 4-degree exit spiral test zone

CONCLUSION

Preliminary modeling involving a simplified coupler arrangement, represented by a solid drawbar, showed that large wheel-rail lateral forces could be generated from large in-train buff forces. Results and observations from the on-track tests showed that the cars did not take up a jackknife orientation as a result of steady state buff forces approaching 300 kips; and thus, no large wheel-rail lateral forces were generated.

Modifications were made to the coupler model resulting in predicted performance more closely matched to the coupler behavior measured during the on-track tests.

Future modeling efforts planned include expanding the simulation matrix to evaluate higher buff loads and also introducing transient longitudinal forces to replicate transient longitudinal input, such as may result from run-in.

References

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