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Impact Simulations of Cars with 15-inch End-of-Car Cushioning Units

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Summary

Transportation Technology Center, Inc. (TTCI) conducted simulations using the Train Operation and Energy Simulator (TOES™) and NUCARS®* to analyze car-to-car impacts and evaluate the performance characteristics of 15-inch stroke end-of-car cushioning (EOCC) units. The analyses included a series of car-to-car impact models to assess the accuracy of their ability to simulate Association of American Railroads (AAR) M-921B type events. The analyses included buff impacts similar to the M-921B impact performance tests and draft impacts similar to the M-921B train action test. Results from the TOES and NUCARS simulations were compared and benchmarked against measured impact data. Both models were found to reasonably represent M-921B style impacts and showed generally good agreement for buff impact conditions up to 8 mph. At higher impact speeds, the displacement stroke exceeded the 15-inch limit, and the simulated coupler force results diverged between the models due to limitations of the TOES EOCC model.

Impact simulations are not common applications of TOES and NUCARS. Special modeling methodologies were developed to represent the impact events using both simulation programs. A NUCARS model of a 15-inch EOCC unit with a 100-kip preload was developed using manufacturer data from impact tests. The EOCC unit model was then inserted into the full NUCARS impact model and simulated to the AAR's M921-B standard. Results from the simulations showed good agreement with measured data from different buff and draft impacts. The NUCARS M-921B impact model was then modified to simulate an impact between two cars equipped with 15-inch EOCC units in order to provide a direct comparison with TOES simulations.

Future work will include simulations conducted using the updated EOCC characteristics to evaluate revenue service performance. Similar simulations and comparisons will also be performed to evaluate 10-inch EOCC units. This effort is part of the AAR Strategic Research Initiative on dynamic load environment of train equipment.

*NUCARS® is a registered trademark of Transportation Technology Center, Inc.

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INTRODUCTION

TTCI conducted simulations to analyze car-to-car impacts and evaluate the performance characteristics of cushioning units under the AAR's Strategic Research Initiatives (SRI) program. This *Technology Digest* details the development of different models for simulating car-to-car impacts and the analysis of coupler forces resulting from these impact simulations. End-of-car cushioning (EOCC) units are a type of long travel hydraulic draft systems intended to protect equipment and lading by absorbing energy during car-to-car impacts. EOCC units absorb energy by forcing oil from the high-pressure cylinder to the surrounding casing through various preloaded orifices over a long displacement stroke, typically 10 or 15 inches. EOCC units provide protection of equipment in yard environments where impacts between cars generate large coupler forces and accelerations, but they can also create slack action issues during normal train operations due to their long travel.

In-train forces typically are simulated using a longitudinal train dynamics program, such as TTCI's TOES software. TOES is an effective tool for evaluating train dynamics given different environmental and train handling conditions, but the program has potential limitations when modeling EOCC units. The TOES program uses a simplified fluid dynamics representation of EOCC devices to approximate the behavior of the devices. TOES also assumes equal, mirrored displacements between draft gears of two adjacent, coupled cars to simplify the calculation. This assumption has little effect on the results of an entire train; however, it can be problematic when evaluating coupler forces and displacements for a specific coupling in a train between dissimilar draft systems, such as impact simulations according to AAR's M-921B standard.[1] In those situations, multi-body dynamics programs, such as TTCI's NUCARS software, can provide better insights into the interactions between cars.

SIMULATIONS

TTCI conducted a series of car-to-car impact models using TOES and NUCARS to evaluate EOCC unit performance and to assess accuracy in simulating M-921B type impacts. A typical M-921B impact performance test to evaluate the buff performance of a 15-inch EOCC unit includes the following:

- Hammer car loaded to 263,000 pounds gross rail load
  - Load depends on device capacity tested
- Anvil car loaded to 220,000 pounds
  - Coupled to a backup string of cars
- Two backup cars, each loaded to 220,000 pounds
  - Coupled to one another and the anvil car
  - Hand brake set on the last car of the string

The general setup for simulations of the M-921B impact performance tests is shown Figure 1. The standard impact performance test calls for the hammer car to impact the stationary anvil string at speeds from 1 to 10 mph to evaluate the buff performance of an EOCC unit. The draft performance of a typical 15-inch EOCC unit is evaluated using the train action test from the M-921B standard. The test conditions for the train action tests are similar to the impact performance test except only one car is included in the backup string instead of two cars. For typical impact performance and train action tests, standard friction draft gears are installed in all cars except at either the struck end of the anvil car or the struck end of the hammer car. That location must have the M-921B test EOCC unit installed.

TTCI used measured impact data from impact performance tests and train action tests to characterize 15-inch EOCC units and develop a NUCARS model of the device using the performance characteristics. Impact simulations are not common applications of TOES and NUCARS. In order to simulate impact events, atypical model setups were employed to represent the systems.

TOES™ IMPACT MODEL

TOES normally is used to simulate trains with vehicles coupled in close proximity. In order to model a car-to-car impact similar to the M-921B standard, a TOES consist model was developed containing four vehicles: a hammer car, an anvil car, and two backup string cars. The TOES vehicles were loaded to match the vehicle weights specified in the previous section. For simulations evaluating buff impact performance, the backup string behind the anvil contained two cars. For simulations evaluating draft impact performance, the backup string behind the anvil contained just one car.

A large, free slack condition was introduced between the couplers of the hammer and anvil cars to allow the hammer car to travel independently of the anvil car and backup string. The initial state of the train was then specified so that the hammer car had nonzero velocity and was moving towards the stationary anvil and backup string. After the available free slack between the couplers of the hammer and anvil cars was exhausted, an impact

between the cars occurred in the simulation. The draft system on the struck end of the anvil car was specified to be either a friction draft gear or a 15-inch EOCC unit with a 100-kip preload depending on the specific simulation. All other draft systems in the model were specified as standard friction draft gears from the TOES library.

NUCARS IMPACT MODEL

NUCARS is a multi-body dynamics program that is used to simulate the interactions between a moving vehicle, its components, and the track. The program also can be used as a more general multi-body dynamics model to simulate body-to-body interactions within a system. A NUCARS model also was developed to simulate M-921-B type impacts. The model contained four instances of the standard loaded hopper model from the NUCARS software package to represent the hammer car, anvil car, and two backup string cars. The NUCARS vehicles were loaded to match the previously specified vehicle weights. Similar to the TOES impact model, the NUCARS model contained two backup string cars for buff impact simulations and one backup car in the string for draft impact simulations. Figure 1 shows the NUCARS representation of the M-921B impact performance test.

Coupler bodies were added to the standard loaded hopper model to provide an interface for adjacent cars to interact with one another. A gap connection was included between the couplers of the hammer car and anvil car to allow the hammer car to move independently from the other cars until the point of impact. The coupler bodies were connected to each vehicle using models of either friction draft gear characteristics or 15-inch EOCC unit characteristics. Friction draft gears were modeled in NUCARS using a dry friction slider hysteresis connection in series with a parallel spring-damper. The NUCARS friction draft gear characteristics were set to match the performance envelope of the TOES friction draft gear model.

A NUCARS model of a 15-inch EOCC unit with a 100-kip preload was developed using manufacturer data. The EOCC unit was modeled in NUCARS as a series of staggered damper connections that allow the overall damping of the EOCC model to progressively increase with the stroke. The EOCC unit is able to account for a loss in orifice area as the stroke increases and includes a 100-kip connection preload. With the exception of the draft system on the struck end of the anvil car, all draft systems in the model were specified to be the NUCARS friction draft gear representation. The draft system on the struck end of the anvil car was specified to be the draft system of interest depending on the specific simulation.

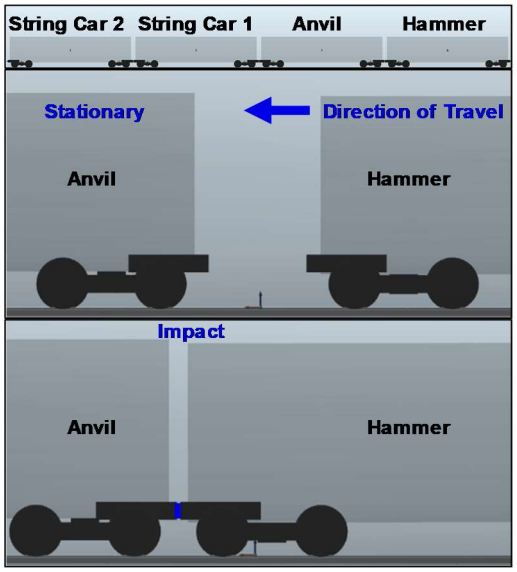

Figure 1. NUCARS model of M921-B impact

The initial positions and speeds of the vehicles in the model were specified similarly to the TOES model. The NUCARS models of the vehicles included active representation of the wheel/rail interface to account for wheel/rail resistance. When the wheel/rail interface calculation is active in NUCARS, the program requires the overall simulation velocity to be nonzero, so the overall simulation velocity was set to a negligible value. The desired initial positions and velocities were then set for each car.

SIMULATION RESULTS

Initial simulations were conducted using cars with friction draft gears only. The friction draft gear model in TOES has been used extensively, and its behavior is better understood than EOCC units. The TOES impact model was used to simulate impacts with friction draft gears only, and the results were benchmarked against previous impact tests performed by AAR.[2] The NUCARS impact model was then used to simulate equivalent M-921B type impacts with only friction draft gears equipped in the cars. The results are compared in Figure 2. TOES and NUCARS simulations yielded nearly identical results for the base case with only friction draft gears. The simulations allowed for a direct comparison of TOES and NUCARS simulation results and provided a modeling base that was expanded on to simulate EOCC unit impacts.

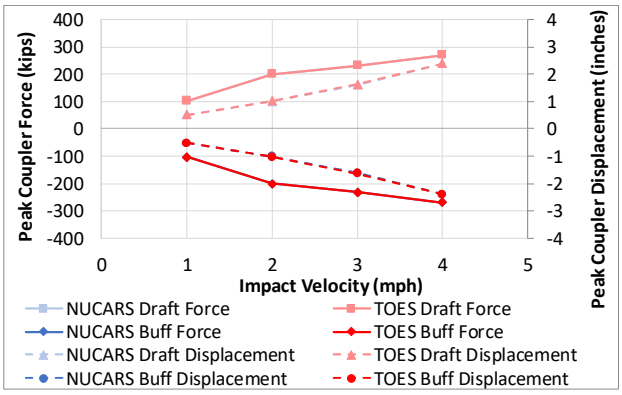

Figure 2. Comparison of TOES and NUCARS simulations for draft gear-to-draft gear impacts

A model of a 15-inch EOCC unit was then developed in NUCARS using supplier data from M-921B buff and draft impacts. The NUCARS model of the EOCC unit was then inserted into the struck end of the anvil car and simulated using the full impact model according to the AAR's M921-B standard.[4] Results from the simulations were compared to measured data from various buff and draft impacts (Figure 3). Dynamic NUCARS impact simulations showed reasonable agreement with measured coupler forces and displacements.

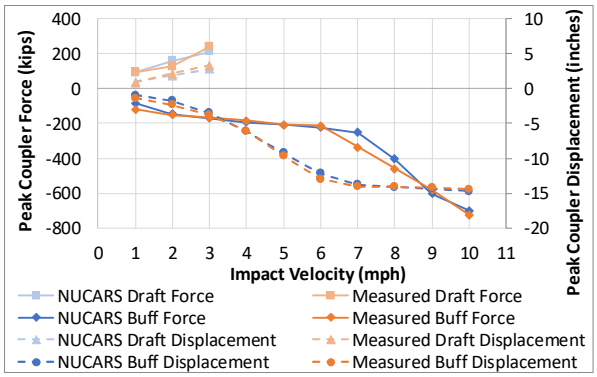

Figure 3. Comparison of test data and NUCARS simulations for EOCC-to-draft gear impacts

The NUCARS impact model was then modified to examine EOCC-to-EOCC impacts, similar to TOES simulations. Results from the EOCC-to-EOCC impact simulations were used to improve characteristics of the TOES EOCC model using comparable NUCARS simulations. Results from the simulations were compared for buff and draft impacts at different speeds (Figure 4).

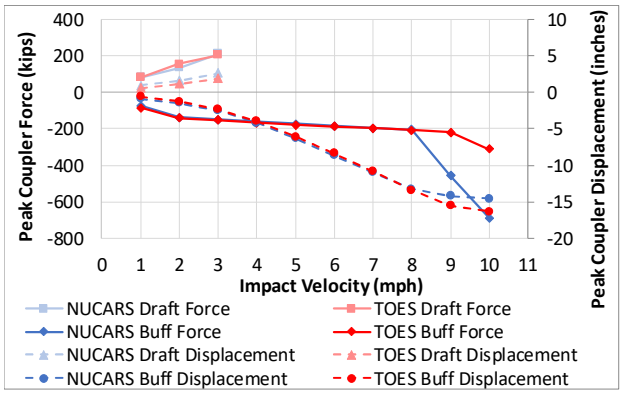

Figure 4. Comparison of TOES and NUCARS simulations for EOCC-to-EOCC impacts

Results of equivalent NUCARS and TOES impact simulations showed generally good agreement for speeds up to 8 mph. At this point, the displacement stroke exceeded the 15-inch limit, and the coupler force results diverged due to limitations of the TOES EOCC model.

CONCLUSION

Impact simulation environments were constructed using NUCARS and TOES modeling software. Measured data from M921-B buff and draft impact tests were compared to simulation results from NUCARS and TOES simulations. NUCARS results agreed well with test data. Results of equivalent NUCARS and TOES impact simulations showed generally good agreement for impact speeds up to 8-mph speed or 250-kip forces. At this point, the coupler force results diverged due to limitations of the TOES EOCC model. NUCARS and TOES models reasonably represented M-921B style impacts. Future work will include simulations conducted using the updated EOCC characteristics to evaluate revenue service performance. Similar simulations and comparisons will also be performed to evaluate 10-inch EOCC units.

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