UNITED STATES DEPARTMENT OF ENERGY ATLAS TRAIN MULTIPLE CAR POST-TEST ANALYSIS REPORT

for United States Department of Energy

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Proprietary Report

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Executive Summary

MxV Rail, a subsidiary of the Association of American Railroads (AAR), performed post-test modeling of the U.S. Department of Energy (DOE) Atlas 12-axle cask-carrying railcar, the Buffer railcar, and the Rail Escort Vehicle (REV). The Atlas and Buffer railcars were developed as part of the DOE Atlas Railcar Project to meet the need for future large-scale rail transport of spent nuclear fuel and high-level radioactive waste. The modeling was performed per the requirements of the AAR *Manual of Standards and Recommended Practices (MSRP)*, Standard S-2043, "Performance Specification for Trains Used to Carry High-Level Radioactive Material," revised 2017.[1]

Although this work was suggested due to the results found during Multiple Car Testing, nothing within this report touches upon hypothetical effects of car-to-car interaction. Post-test modeling following multiple car tests is not necessarily required as part of the standard S-2043 approval process. During the revenue service portion of multiple car tests, the train encountered rail profile conditions that caused curving issues not observed during single car tests. The wheel profile was changed from AAR-1B narrow flange to AAR-2A narrow flange to address the problem. The AAR-1B wheel profile was the standard when the railcars were designed, and the AAR-2A replaced AAR-1B as the standard in 2020. The AAR Equipment Engineering Committee (EEC) S-2043 task force requested that simulations of select single car test regimes (see Appendix A) be performed to evaluate how the wheel profile change affects other areas of performance where tests were already completed. The results of these simulations are presented in this report.

With the AAR-2A profiles, both the REV and Atlas railcar met Standard S-2043 criteria for simulations of the Alps curve but with the AAR-1B profiles, neither met all criteria. The AAR-2A profile simulation predictions were slightly worse than the AAR-1B profile predictions for the Atlas railcar with minimum test load in number (No.) 7 crossover (truck side L/V ratio = 0.51 compared to 0.49) and the REV in the Class 4 ride quality simulations (standard deviation of lateral acceleration =0.14 g compared to 0.11 g). In all other regimes, simulation predictions with both profiles either met criteria or were the same or better with the AAR-2A wheel profile.

The following tables summarize the modeling results for the empty Atlas railcar (GRL 222,050 pounds), the Atlas railcar with minimum test load (GRL 421, 025 pounds), the Atlas railcar with maximum test load (712,450 pounds), the REV, and the Buffer car.

Summary of simulation results for the empty Atlas railcar

Standard S-2043 Section	Met/Not Met	
	Simulations Idealized AAR-1B Wheels (Idealized KR Hunting)	Simulations Idealized AAR-2A Wheels
5.5 Dynamic Tests		
4.3.11.3/5.5.7 Hunting	Met	Met
5.5.10 Dynamic Curving	Met	Met

Summary of simulation results for the Atlas railcar with the minimum test load

Standard S-2043 Section	Met/Not Met	
	Simulations Idealized AAR-1B Wheels (Idealized KR Hunting)	Simulations Idealized AAR-2A Wheels
5.5 Dynamic Tests		
Alps 10-degree Curve	Not Met Clockwise (CW) Maximum truck-side L/V ratio: = 0.74, S-2043 limit = 0.50 Counterclockwise (CCW) Maximum wheel L/V ratio: = 0.81, S-2043 limit = 0.80 CCW Maximum truck-side L/V ratio: = 0.75, S-2043 limit = 0.50	Met
4.3.11.3/5.5.7 Hunting	Not Met Std dev carbody lateral acceleration (g): = 0.14, S-2043 limit = 0.13	Met
5.5.10 Dynamic Curving	Met	Met
4.3.11.7/5.5.17 Special Trackwork, No 7 Crossovers	Met	Not Met A-End Leading Maximum truck-side L/V ratio: = 0.51, S-2043 limit = 0.50 B-End Leading Maximum truck-side L/V ratio: = 0.51, S-2043 limit = 0.50

Summary of simulation results for the Atlas railcar with the maximum test load

Standard S-2043 Section	Met/Not Met	
	Simulations Idealized AAR-1B Wheels (Idealized KR Hunting)	Simulations Idealized AAR-2A Wheels
5.5 Dynamic Tests		
Alps 10-degree Curve	Not Met CW Maximum truck-side L/V ratio: = 0.71, S-2043 limit = 0.50 CCW Maximum truck-side L/V ratio: = 0.73, S-2043 limit = 0.50	Met
4.3.11.3/5.5.7 Hunting	Met	Met
5.5.10 Dynamic Curving	Met	Met

4.3.11.7/5.5.17 Special Trackwork, No 7 Crossovers	Met	Met

Summary of simulation results for the REV

Standard S-2043 Section	Met/Not Met Simulations Idealized AAR-1B Wheels (Idealized KR Hunting)	Met/Not Met Simulations Idealized AAR-2A Wheels
5.5 Dynamic Tests		
4.3.11.3/5.5.7 Hunting	Met	Met
5.5.9 Yaw and Sway	Not Met Peak-to-peak carbody lateral acceleration (g): = 0.83, S-2043 limit = 0.60 Maximum carbody lateral acceleration (g): = 0.53, S-2043 limit = 0.35	Not Met Peak-to-peak carbody lateral acceleration (g): = 0.71, S-2043 limit = 0.60 Maximum carbody lateral acceleration (g): = 0.38, S-2043 limit = 0.35
5.5.10 Dynamic Curving	Met	Met
4.3.10.25.5.15 Curving with Single Rail Perturbation	Met	Met
4.3.11.7/5.5.17 Special Trackwork, No 7 Crossovers	Not Met Maximum truck-side L/V ratio: = 0.54, S-2043 limit = 0.50	Not Met Maximum truck-side L/V ratio: = 0.54, S-2043 limit = 0.50
4.3.12 Ride Quality	Not Met Class 4 Track: Maximum carbody vertical acceleration (g): = 0.70, S-2043 limit = 0.60	Not Met Class 4 Track: Std dev carbody lateral acceleration (g): = 0.14, S-2043 limit = 0.13 Maximum carbody vertical acceleration (g): = 0.70, S-2043 limit = 0.60

Summary of simulation results for the Buffer car

Standard S-2043 Section	Met/Not Met Simulations Idealized AAR-1B Wheels (Idealized KR Hunting)	Met/Not Met Simulations Idealized AAR-2A Wheels
5.5 Dynamic Tests		
4.3.11.3/5.5.7 Hunting	Met	Met
5.5.10 Dynamic Curving	Met	Met

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1.0 INTRODUCTION

As part of the U.S. Department of Energy (DOE) Atlas Railcar Project, the Atlas and Buffer railcars were developed and tested to meet the need for future large-scale rail transport of spent nuclear fuel and high-level radioactive waste. The DOE collaborated with the United States Naval Nuclear Propulsion Program (NNPP) to purchase a Rail Escort Vehicle (REV) that the NNPP had designed and tested. In July 2018, the DOE contracted MxV Rail, a subsidiary of the Association of American Railroads (AAR), to perform 1) dynamic modeling and certification testing on its Atlas and Buffer railcars and 2) post-test modeling of the DOE Atlas 12-axle cask-carrying railcar, the Buffer railcar, and the REV. The modeling was performed per the requirements of the AAR *Manual of Standards and Recommended Practices (MSRP)*, Standard S-2043, "Performance Specification for Trains Used to Carry High-Level Radioactive Material," revised 2024.[1] The modeling described in this report was performed to assist in resolving performance issues found during revenue service testing of the high-level radioactive waste transport consist as described in "Certification Testing of United States Department of Energy Atlas Train Multiple Car Test Report."[2]

Post-test modeling following multiple car tests is not necessarily required as part of the Standard S-2043 approval process. The train encountered rail profile conditions during the revenue service portion of multiple car tests that caused curving issues not observed during single car tests. The wheel profile was changed from AAR-1B narrow flange to AAR-2A narrow flange to address the problem. The AAR-1B wheel profile was the standard when the railcars were built, but the AAR-2A replaced AAR-1B as the standard in 2020. The AAR Equipment Engineering Committee (EEC) Standard S-2043 task force requested that simulations of select single car test regimes (see Appendix A) be performed to evaluate how the wheel profile change affects other areas of performance where tests were already completed. The results of these simulations are presented in this report.

Simulation predictions were made using inputs created with measured track geometry. MxV Rail's experience has shown that simulations with measured track geometry produce better predictions of car performance than are obtained with analytic track inputs created with mathematical functions. Because the measured track geometry inputs contain short wavelengths that cause spurious peaks in the data, the 50-millisecond and 3-foot analysis windows described in AAR Chapter 11 and Standard S-2043 are used when analyzing data to produce the most realistic results. Table cells highlighted in yellow indicate data that does not meet the Standard S-2043 criteria.

2.0 DESCRIPTION OF MODEL COMPONENT VARIATION

The first revenue service test (Standard S-2043, paragraph 6.3) was performed in October 2022 between Avondale, CO, and the 10-degree curve at Milepost 274 of the BNSF's Twin Peaks subdivision near Alps, NM. MxV Rail selected the 10-degree curve (Figure 1), referred to in this report as the Alps curve, for the revenue service 10-degree curve test. This curve was selected to satisfy the requirements of Standard S-2043, paragraph 6.3.1.2. The Alps curve had the following characteristics:

- 10-degree curve

- Body length of about 1,500 feet.
- Spiral lengths of about 300 feet.
- 2.25-inches superelevation.
- The north end of the curve was in a grade of about 0.93 percent, there was a section with 0.26 percent grade in the body of the curve, and the south end was in a grade of 0.84 percent. Grades were downhill when travelling north to south.
- The track used concrete ties with elastic fasteners and appeared to be in very good condition.
- Balance speed was 18 mph and timetable speed was 25 mph.

Figure 1. Location of the Alps 10-degree curve

During the 2022 tests, truck-side L/V ratios on the Atlas and REV exceeded the Standard S-2043 criterion in many of the 4-degree or tighter curves between Trinidad, Colorado, and the siding at Folsom, New Mexico. The siding at Folsom is approximately 10-miles beyond the Alps curve. Although this report focuses on the Alps Curve, the behaviors modeled will apply to the other exceptions as found on nearby curves in the Twin Peaks subdivision.

MxV Rail investigated several possible solutions to reduce the truck-side L/V ratios using the vehicle dynamics models developed and validated during both the design phase and the single car testing phase of the Standard S-2043 process. The potential solutions investigated include:

- Changing the longitudinal and lateral pedestal clearance in the trucks
- Changing the truck center plate friction
- Changing the primary suspension longitudinal stiffness
- Changing the primary suspension lateral stiffness
- Changing from the AAR-1B narrow flange wheel profiles to the AAR-2A narrow flange wheel profiles

Based on the modeling results, the only potential solution that appeared to have a significant effect on the vehicle curving performance was changing from the AAR-1B narrow flange wheel profile to the AAR-2A narrow flange wheel profile.[3,4] Figure 2 shows the difference between how the two wheel-tread profiles contact the outside rail in the Alps curve. The AAR-1B narrow flange design profile has two distinct points of wheel and rail contact, one on the tread and one on the flange, and a significant distance (nearly 1.4 inches) in between the points where no contact occurs. Having two contact points reduces the steering forces generated by the wheelset.[5] The reduced steering forces are not adequate to rotate the trucks and axles into the best position for curve negotiation. The AAR-2A profile has a single point of contact with the high rail of the Alps curve, allowing for larger steering forces that result in better positioning of the trucks and axles, and thereby improving the steering performance.

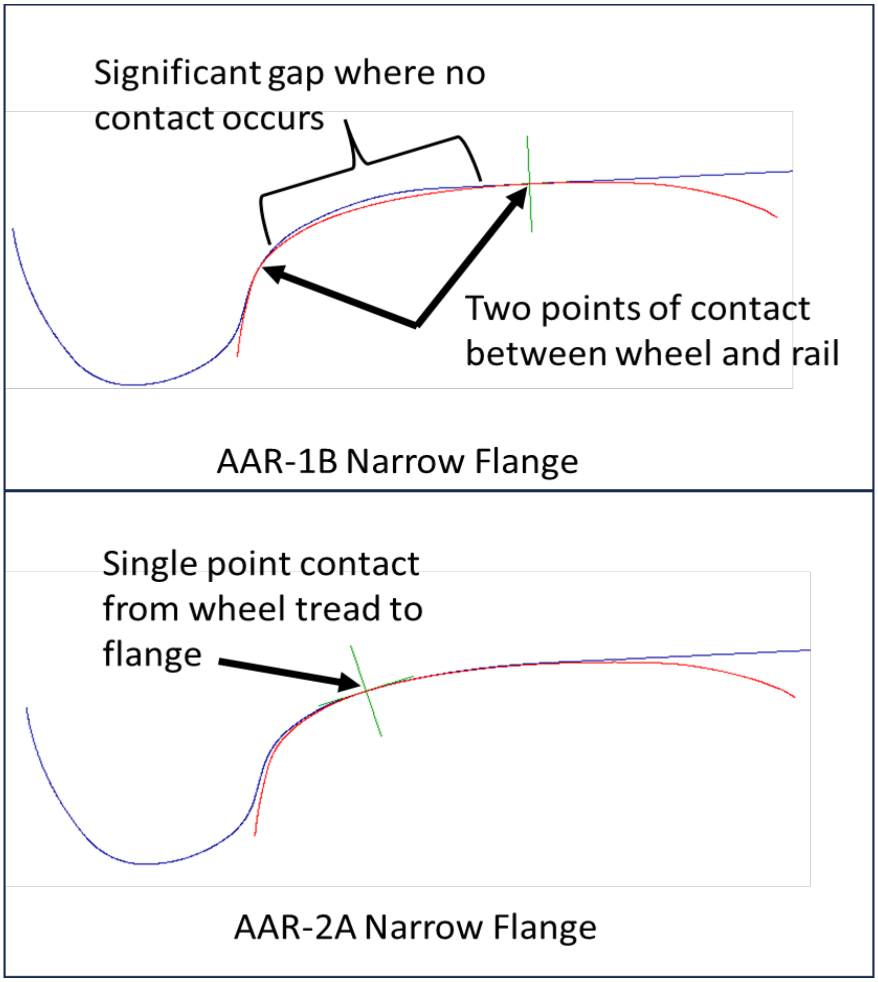

Figure 2. Comparison of the contact conditions of the AAR-1B narrow flange and the AAR-2A narrow flange wheel profiles on the outside rail profile measured in the Alps curve

Changing from the AAR-1B narrow flange wheel profile to the AAR-2A narrow flange wheel profile significantly improved the test results. Figure 3 shows:

- A histogram of the track curves between Trinidad and the Alps curve
- The number of curves where the REV did not meet the truck-side L/V ratio criterion with AAR-1B narrow flange wheel profiles
- The number of curves where the REV did not meet the truck-side L/V ratio criterion with AAR-2A narrow flange wheel profiles

The truck-side L/V ratio results shown in Figure 3 were measured while traveling south with the REV's instrumented truck leading (B-ends of the cars leading). During this portion of the test, the REV did not meet the truck-side L/V ratio criterion for only two out of 88 total curves with the AAR-2A narrow flange profile, indicating a significant improvement over the AAR-1B narrow flange profile where the REV did not meet the criterion for 30 out of 88 total curves.

Compared to the Chapter 11 maximum truck side L/V ratio criterion (0.6) (based on a free body diagram of an *unrestrained* rail[6]), the Standard S-2043 maximum truck side L/V ratio criterion (0.5) is very conservative for reasons that made a rail rollover very unlikely at these levels:

- In reality, a rail is restrained by adjacent trucks, assuming those trucks are applying lower lateral forces to the track than the subject truck.
- Rails are restrained by fasteners connecting the rails to the ties. For the Alps curve, these fasteners are elastic fasteners that apply significant restraint.

The tests with AAR-2A profiles were conducted several months after the tests with AAR-1B profiles. Wheel-rail friction conditions can also affect curving performance, but friction conditions were similar for the two tests. Average friction measured on October 26, 2022, (the day after the AAR-1B test) was 0.44 (top of low rail), 0.53(top of high rail), and 0.29 (gage face of high rail). Average friction measured on June 27 and 29, 2023, (the days of AAR-2A test) was 0.44 (top of low rail), 0.49 (top of high rail), and 0.35 (gage face of high rail). Simulations showed that the truck-side L/V ratio curving performance was more sensitive to the wheel and rail shape than wheel-rail friction conditions.

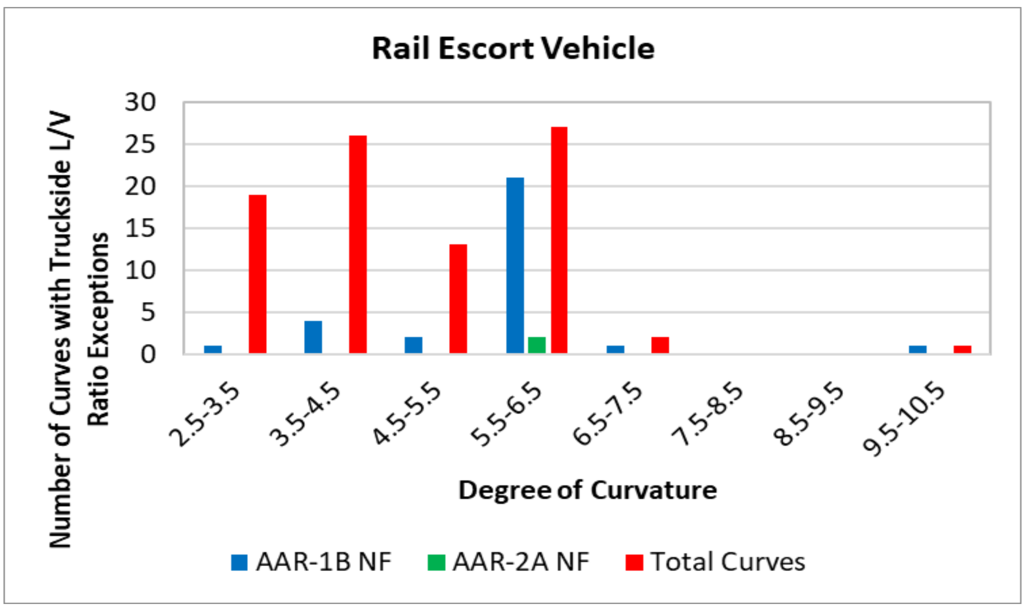

Figure 3. REV truck side L/V ratio curving performance test results going from Trinidad to the Alps curve with the B-end leading

Figure 4 shows a plot of the truck-side L/V ratios for the Atlas railcar with B-end-leading southbound runs in buff and A-end-leading northbound runs in draft while the car operates in the Alps curve. These test runs were performed with AAR-1B narrow flange profiles and repeated with AAR-2A narrow flange profiles. Eight operating permutations exist for each wheel profile on this curve: (north versus south travel direction, A-end versus B-end oriented toward the South, and buff or draft in-train forces). However, only two of the eight were captured before stopping the AAR-1B tests. Therefore, only the Northbound, Draft, B-End South results and the Southbound, Buff, B-End South results will be compared in Figure 4. Based on these exceptions measured with the AAR-1B narrow flange profile, testing was suspended following these test runs to begin investigation of the issue. The graph shows that, for this portion of the runs performed, the Atlas railcar did not meet the truck-side L/V ratio criterion for any of the runs with the AAR-1B narrow flange profile, but it did meet the criterion for the runs shown (2 of 8 permutations) with the AAR-2A narrow flange profile. The highest truck-side L/V ratio for each run, regardless of wheel profile, occurred on the high rail side of the train.

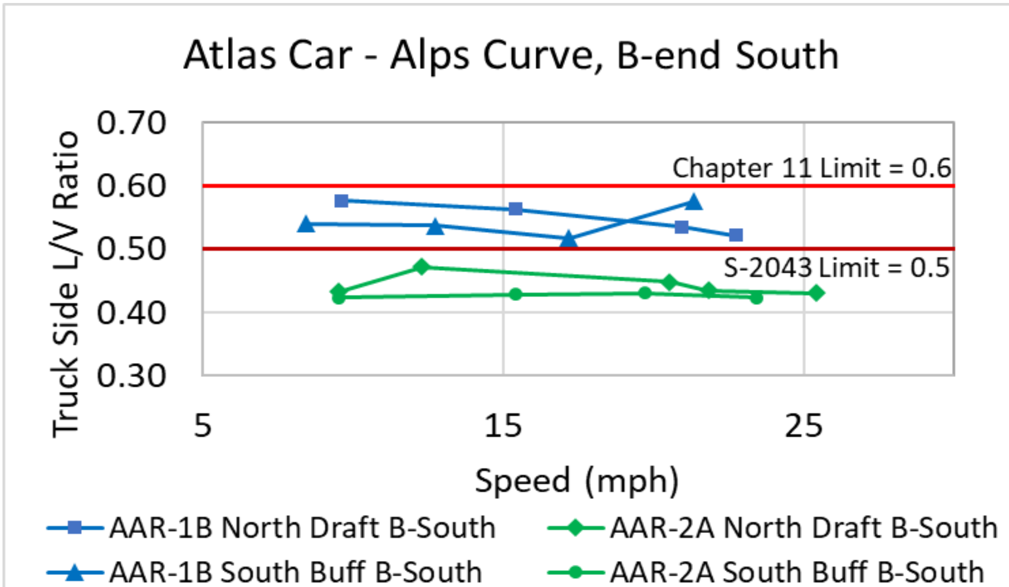

Figure 4. Comparison of Atlas railcar truck-side L/V ratio test results with AAR-1B narrow flange wheel profiles and with AAR-2A narrow flange wheel profiles in the Alps test curve

3.0 OBJECTIVE

The objective of this report is to compare the predicted performance of the Atlas railcar, the Buffer car, and the REV when each is configured with AAR-1B narrow flange profile wheels (and the KR profile for the hunting regime to represent a moderately worn AAR-1B) with the predicted performance when the same cars are configured with AAR-2A narrow flange profile wheels.

4.0 REVENUE SERVICE TEST - ALPS CURVE MODEL AND TEST DATA

The revenue service tests were initially performed in October 2022 with AAR-1B narrow flange wheel profiles. During these tests, MxV Rail measured many instances of single-wheel L/V ratios and truck-side L/V ratios that did not meet Standard S-2043 criteria. Tests were aborted after approximately a quarter of the test runs had been performed. After much investigation, this performance was attributed to the two-point contact between the AAR-1B wheel and the ground high rail of the curve. The AAR-2A wheel did not produce severe two-point contact with the ground profile. In June 2023, MxV Rail repeated the tests using AAR-2A narrow flange wheel profiles. The change from an AAR-1B narrow flange profile to an AAR-2A narrow flange profile dramatically improved the performance of the train and is described in Section 2.0.

Simulations of the Alps curve were performed using measured track geometry and measured rail profiles from the test curve. Simulations used a coefficient friction of 0.5 on the rail head and 0.2 on the gage face of the inside and outside rails, matching lubrication condition 2 from

Standard S-2043, paragraph 4.3.11.5. The results of the post-test modeling of the Atlas railcar and REV predicted the highest L/V ratios with lubrication case 2.

4.1 Atlas Minimum Test Load

Table 1 shows the worst-case simulation predictions and the test results for the Atlas railcar with the minimum test load on the Alps 10-degree curve traveling north (CW direction). The model was run with two different wheel profiles, AAR-1B and AAR-2A. The testing on the Alps 10-degree curve was performed with wheels having AAR-1B profiles, and later, with wheels that were cut to AAR-2A profiles. The model configured with the AAR-2A wheel profiles produced much lower maximum wheel and truck-side L/V ratios than the model configured with AAR-1B wheel profiles (produces the highest maximum L/V ratios). In summary, modeling results predicted the truck-side L/V ratios would be dramatically better (~50 percent) for an AAR-2A wheel, compared to the AAR-1B wheel. Tests showed a significant (~20 percent) improvement, indicating the AAR-2A brought truck side L/V ratios within the Standard S-2043 limit. Other criteria showed mixed results but did not exceed allowable limits.

Figure 5 plots the maximum truck-side L/V ratio against the speed for the simulations and tests of the Atlas railcar with the minimum test load traveling north on the Alps 10-degree curve. The plot compares the predicted performance of the Atlas railcar based on 1) simulations of the car fitted with wheels having AAR-2A profiles, 2) simulations of the car fitted with wheels having AAR-1B profiles, 3) test results of the car fitted with wheels having AAR-1B profiles, and 4) test results of the car fitted with wheels having AAR-2A profiles. The simulation predictions and test results with the AAR-2A profiles met the Standard S-2043 criteria, while none of the predictions or test results with the AAR-1B profiles met Standard S-2043 criteria.

Eight operating permutations exist for each wheel profile on this curve: (CW versus CCW travel direction, A-end versus B-end leading travel, and buff or draft in-train forces). However, only two of the eight were captured before stopping the AAR-1B tests. Therefore, only the CW travel/A-end leading/draft results will be compared in Table 1 and Figure 5 1) for both AAR-2A and AAR-1B wheels and 2) for test versus modeling. (Data for all the other AAR-2A test conditions are shown in the test report.[2])

Table 1. Comparison of test and simulation results for the Atlas railcar with the minimum test load traveling north on the Alps 10-degree curve (worst response across all operating speeds)

Criterion	S-2043 Limiting Value	Alps 10-degree curve, CW			
		Model AAR-2A	Model AAR-1B	Test AAR-2A	Test AAR-1B
Maximum carbody roll angle (degree)	4.0	0.3	0.3	0.2	0.2
Maximum wheel L/V ratio	0.80	0.61	0.80	0.76	0.77
Maximum truck side L/V ratio	0.50	0.34	0.74	0.47	0.58
Minimum vertical wheel load (%)	25%	57%	58%	60%	52%
Peak-to-peak carbody lateral acceleration (g)	1.3	0.2	0.3	0.20	0.16
Maximum carbody lateral acceleration (g)	0.75	0.13	0.15	0.14	0.10

Criterion	S-2043 Limiting Value	Alps 10-degree curve, CW			
		Model AAR-2A	Model AAR-1B	Test AAR-2A	Test AAR-1B
Std dev carbody lateral acceleration (g)	0.13	0.02	0.03	0.03	0.03
Maximum carbody vertical acceleration (g)	0.90	0.23	0.23	0.20	0.21
Maximum vertical suspension deflection (%)	95%	21%	21%	11%	10%

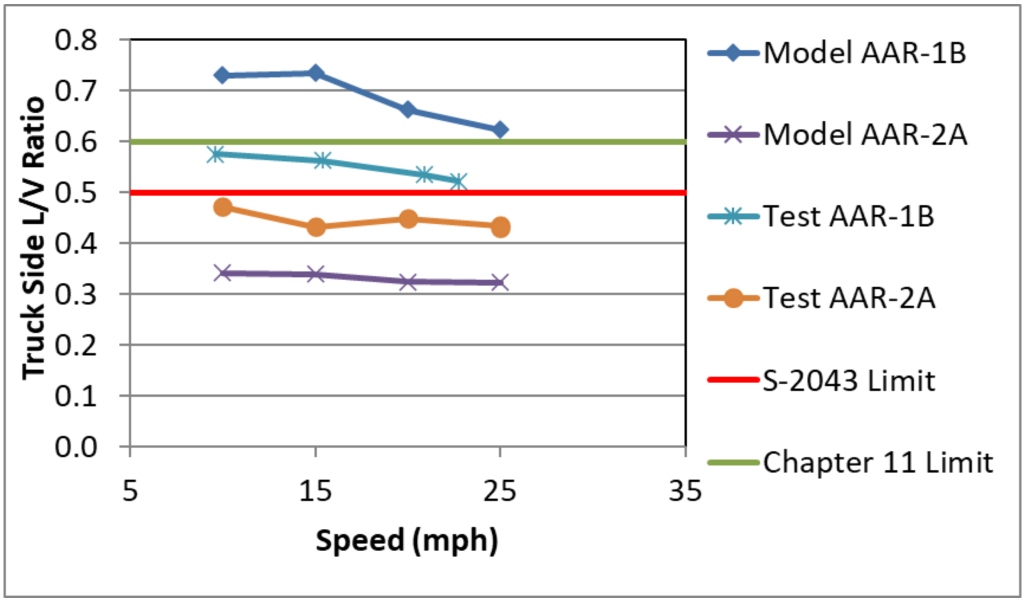

Figure 5. Predicted maximum truck-side L/V ratios versus operating speed for the Atlas railcar with the minimum test load on the Alps 10-degree curve traveling north compared with actual test results

As stated above, only two of eight operating permutations were captured before stopping the AAR-1B tests. The case for the train traveling south (CCW/B-end leading/buff load) is discussed below and shown in Table 2, Figure 6, and Figure 7 for both 1) AAR-2A and AAR-1B wheels and 2) for test versus modeling. In essence, the CCW runs show the same relative performance improvement due to the AAR-2A wheel as the CW runs.

Table 2 shows the worst-case simulation predictions and test results for the Atlas railcar with the minimum test load on the Alps 10-degree curve traveling south (CCW direction). Like the CW (northbound) case, the model and test configured with the AAR-2A wheel profiles produces much lower maximum wheel and truck-side L/V ratios than the model and test configured with AAR-1B wheel profiles. The actual L/V ratios recorded during the test with the AAR-2A profile are higher than those predicted by the model, but both the maximum wheel and the maximum truck-side L/V ratios remained below the Standard S-2043 limit. During testing, the recorded maximum peak-to-peak carbody lateral acceleration and maximum carbody vertical acceleration were both lower than what was predicted by the model.

Figure 6 plots the maximum wheel L/V ratio against speed for the simulations and tests of the Atlas railcar with the minimum test load traveling south on the Alps 10-degree curve. The plot compares 1) simulations of the car fitted with wheels having idealized AAR-2A profiles, 2) simulations of the car fitted with wheels having idealized AAR-1B profiles, 3) test results of the car fitted with wheels having AAR-1B profiles, and 4) test results of the car fitted with wheels having AAR-2A profiles. The maximum wheel L/V ratio of the model configured with the idealized AAR-1B profiles starts out just over the Standard S-2043 limit at 10 mph and remains at or very close to the limit for all speeds simulated. The wheel L/V ratios for the tests with AAR-1B profiles and both the tests and the model configured with the AAR-2A profile all meet the Standard S-2043 criterion at all speeds.

Figure 7 plots the maximum truck-side L/V ratio against the speed for the simulations and tests of the Atlas railcar with the minimum test load traveling south on the Alps 10-degree curve. The plot compares 1) simulations of the car fitted with wheels having idealized AAR-2A profiles, 2) simulations of the car fitted with wheels having idealized AAR-1B profiles, 3) test results of the car fitted with wheels having AAR-1B profiles, and 4) test results of the car fitted with wheels having AAR-2A profiles. The simulation predictions and results for tests performed with the AAR-2A profiles met the Standard S-2043 criteria, while the simulation predictions and results for tests performed with the AAR-1B profiles did not meet Standard S-2043 criteria.

Counterclockwise (southbound) runs were only done in buff with B-end leading during tests when the cars were equipped with AAR-1B wheel profiles. Only data for CCW tests performed in buff with the B-end leading and the car equipped with AAR-2A profiles are shown in this section. Tests with the AAR-2A profile were also performed in draft with B-end leading and in buff and draft with the A-end leading. Data for the other test directions is shown in the test report.[2]

Table 2. Comparison of test and simulation results for the Atlas railcar with the minimum test load traveling south on the Alps 10-degree curve

Criterion	S-2043 Limiting Value	Alps 10-degree curve, CCW			
		Model AAR-2A	Model AAR-1B	Test AAR-2A	Test AAR-1B
Maximum carbody roll angle (degree)	4.0	0.4	0.4	0.2	0.2
Maximum wheel L/V ratio	0.80	0.62	0.81	0.74	0.73
Maximum truck side L/V ratio	0.50	0.36	0.75	0.43	0.58
Minimum vertical wheel load (%)	25%	58%	58%	65%	57%
Peak-to-peak carbody lateral acceleration (g)	1.3	0.3	0.3	0.16	0.11
Maximum carbody lateral acceleration (g)	0.75	0.14	0.17	0.12	0.09
Std dev carbody lateral acceleration (g)	0.13	0.02	0.03	0.02	0.02
Maximum carbody vertical acceleration (g)	0.90	0.24	0.24	0.10	0.15
Maximum vertical suspension deflection (%)	95%	21%	21%	13%	12%

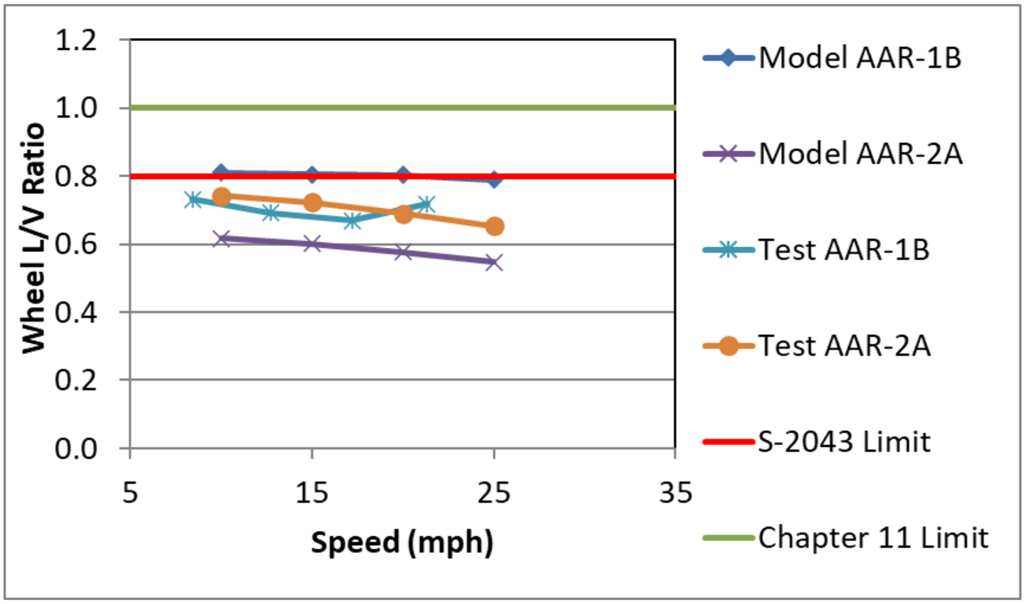

Figure 6. Predicted maximum wheel L/V ratios for the Atlas railcar with the minimum test load on the Alps 10-degree curve traveling south compared with actual test results

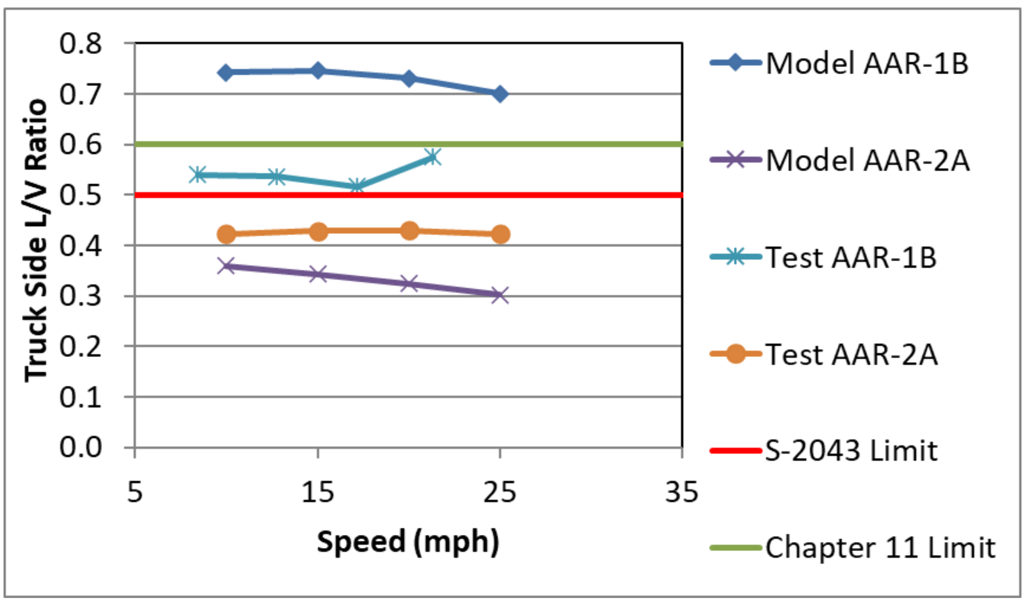

Figure 7. Predicted maximum truck-side L/V ratios for the Atlas railcar with the minimum test load on the Alps 10-degree curve traveling south compared with actual test results

4.2 Atlas Maximum Test Load

Table 3 shows the worst-case simulation predictions for the Atlas railcar with the maximum test load on the Alps 10-degree curve traveling north (CW direction). The model was run with three different wheel profiles, idealized AAR-1B, idealized AAR-2A, and measured AAR-1B profiles. No on-track tests were performed with the maximum test load because the minimum test load was found to have the worst-case curving performance during single car testing, and revenue service tests are only required for one load condition. The modeling results for the maximum test load are being included with measured AAR-1B profiles to demonstrate the range of performance. Similar to the minimum test load cases, the model configured with idealized AAR-1B wheel profiles produces the highest truck-side and wheel L/V ratios with the truck-side L/V ratio falling well above the Standard S-2043 limit. The idealized AAR-1B profiles also produce the lowest minimum vertical wheel load. The model configured with the measured AAR-1B profiles produces lower maximum wheel and truck-side L/V ratios and a slightly higher minimum vertical wheel load, but the truck-side L/V ratio reaches the Standard S-2043 limit. The model configured with the idealized AAR-2A profiles produces much lower maximum wheel and truck-side L/V ratios that fall well below the Standard S-2043 limits. The various predicted accelerations are very similar across all three profiles.

Figure 8 plots the maximum truck-side L/V ratio against the simulation speeds of the Atlas railcar with the maximum test load traveling north on the Alps 10-degree curve. The plot compares the predicted performance of the Atlas railcar based on simulations of the car fitted with wheels having 1) idealized AAR-2A profiles, 2) idealized AAR-1B profiles, and 3) measured AAR-1B profiles. The predicted performance of the AAR-2A profiles is much better than either the idealized or the measured AAR-1B profiles. The truck-side L/V ratios predicted for the measured AAR-1B profiles are at or a little below the Standard S-2043 limit at all speeds simulated, while the predicted L/V ratios for the idealized AAR-1B profiles are all above the Standard S-2043 limit as well as above the Chapter 11 limit (0.6) for the majority of the speeds simulated.

Table 3. Comparison of test and simulation results for the Atlas railcar with the maximum test load traveling north on the Alps 10-degree curve

Criterion	S-2043 Limiting Value	Alps 10-degree curve, CW		
		Model AAR-2A	Model AAR-1B	Model Measured AAR-1B
Maximum carbody roll angle (degree)	4.0	0.2	0.2	0.2
Maximum wheel L/V ratio	0.80	0.55	0.76	0.71
Maximum truck-side L/V ratio	0.50	0.29	0.71	0.50
Minimum vertical wheel load (%)	25%	64%	61%	63%
Peak-to-peak carbody lateral acceleration (g)	1.3	0.3	0.3	0.3
Maximum carbody lateral acceleration (g)	0.75	0.15	0.16	0.15
Std dev carbody lateral acceleration (g)	0.13	0.03	0.04	0.03
Maximum carbody vertical acceleration (g)	0.90	0.27	0.27	0.26
Maximum vertical suspension deflection (%)	95%	46%	46%	46%

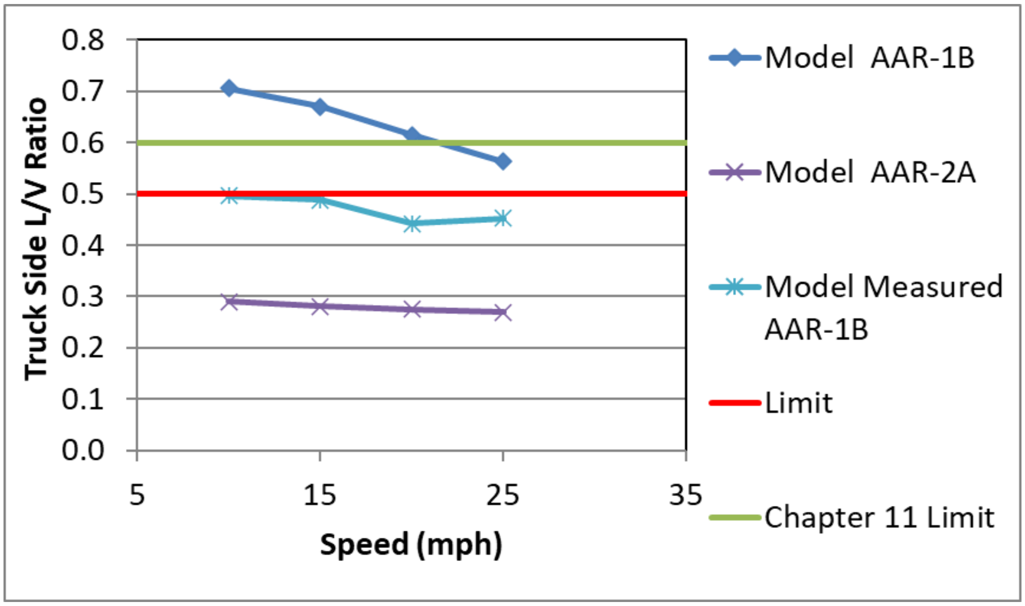

Figure 8. Predicted maximum truck-side L/V ratios for the Atlas railcar with the maximum test load on the Alps 10-degree curve traveling north

Table 4 shows the worst-case simulation predictions for the Atlas railcar with the maximum test load on the Alps 10-degree curve traveling south (CCW direction). The order of performance for the southbound case is the same as the northbound case. The model configured with idealized AAR-1B wheel profiles produces the highest wheel and truck-side L/V ratios with the truck-side L/V ratio well above the Standard S-2043 limit. The idealized AAR-1B profiles also produce the lowest minimum vertical wheel load. The model configured with the measured AAR-1B profiles produces lower maximum wheel and truck-side L/V ratios and a slightly higher minimum vertical wheel load, but the truck-side L/V ratio does reach the Standard S-2043 limit. The model configured with the idealized AAR-2A profiles produces much lower maximum wheel and truck-side L/V ratios. The predicted accelerations are very similar for the three profiles.

Figure 9 plots the maximum truck-side L/V ratio against the speed for various simulations of the Atlas railcar with the maximum test load traveling south on the Alps 10-degree curve. The plot compares the predicted performance of the Atlas railcar based on simulations of the car fitted with wheels having 1) idealized AAR-2A profiles, 2) idealized AAR-1B profiles, and 3) measured AAR-1B profiles. The predicted performance of the AAR-2A profiles is much better than either the idealized or the measured AAR-1B profiles. Like the predicted performance for the northbound runs, the predicted performance of the AAR-2A profiles for the southbound runs is much better than either the idealized or the measured AAR-1B profiles. The truck-side L/V ratios predicted for the measured AAR-1B profiles are below the Standard S-2043 limit at all speeds simulated. The truck-side L/V ratios predicted for the idealized AAR-1B profiles are all above both the Standard S-2043 and the Chapter 11 limits for all the simulated speeds.

Table 4. Comparison of simulation results for the Atlas railcar with the maximum test load traveling south on the Alps 10-degree curve

Criterion	S-2043 Limiting Value	Alps 10-degree curve, CCW		
		Model AAR-2A	Model AAR-1B	Model Measured AAR-1B
Maximum carbody roll angle (degree)	4.0	0.3	0.3	0.3
Maximum wheel L/V ratio	0.80	0.54	0.79	0.73
Maximum truck-side L/V ratio	0.50	0.25	0.73	0.50
Minimum vertical wheel load (%)	25%	65%	63%	64%
Peak-to-peak carbody lateral acceleration (g)	1.3	0.4	0.4	0.3
Maximum carbody lateral acceleration (g)	0.75	0.20	0.19	0.19
Std dev carbody lateral acceleration (g)	0.13	0.03	0.04	0.03
Maximum carbody vertical acceleration (g)	0.90	0.29	0.30	0.29
Maximum vertical suspension deflection (%)	95%	44%	44%	43%

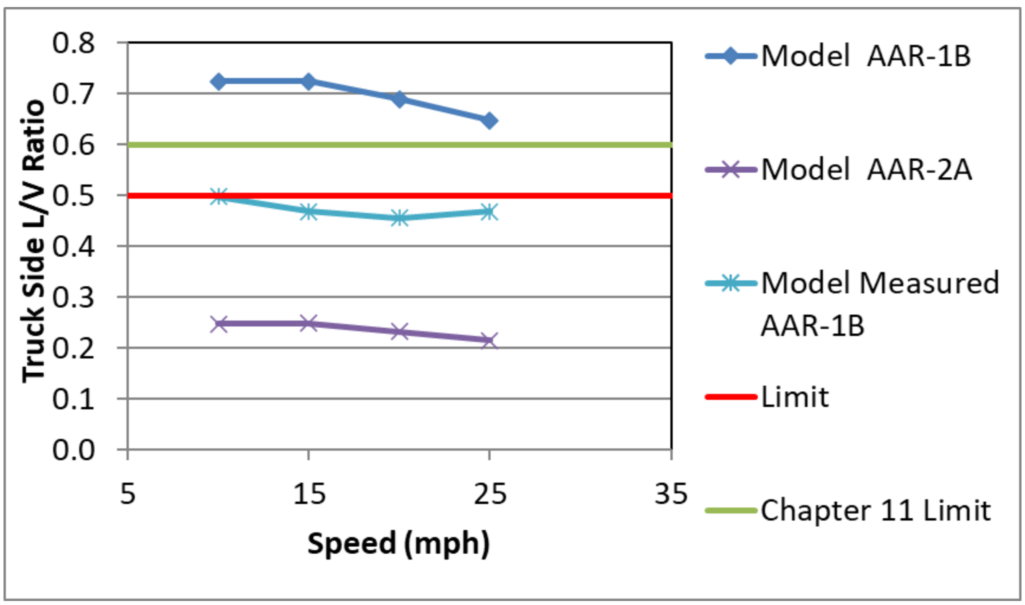

Figure 9. Predicted maximum truck-side L/V ratios for the Atlas railcar with the maximum test load on the Alps 10-degree curve traveling south

4.3 REV

Table 5 shows the worst-case simulation predictions and the test results for the REV on the Alps 10-degree curve traveling north (CW direction). The model was run with two different wheel profiles, idealized AAR-1B and idealized AAR-2A. The testing on the Alps 10-degree curve was performed with AAR-1B profile wheels, and later, with wheels that were cut to AAR-2A profiles. The model configured with the AAR-2A wheel profiles produced much lower maximum wheel and truck-side L/V ratios than the model configured with idealized AAR-1B wheel profiles (produces the highest maximum L/V ratios). The L/V ratios measured with AAR-1B profiles during the test were less than what was predicted with the idealized AAR-1B profile and were equal to the S-2043 maximum limit. The actual L/V ratios recorded with the AAR-2A profiles during the test were higher than those predicted by the model for the AAR-2A profile but met the Standard S-2043 limit for the test condition shown. The minimum vertical wheel load and the maximum carbody lateral and vertical accelerations recorded during testing were higher than what the model predicted.

Figure 10 plots the maximum truck-side L/V ratio against the speed for the simulations and tests of the REV traveling north on the Alps 10-degree curve. The plot compares the predicted performance of the REV based on 1) simulations of the car fitted with wheels having idealized AAR-2A profiles, 2) simulations of the car fitted with wheels having idealized AAR-1B profiles, 3) test results of the car fitted with wheels having AAR-1B profiles, and 4) test results of the car fitted with wheels having AAR-2A profiles. The simulation predictions with AAR-2A profiles and test results with both AAR-1B and AAR-2A profiles met the Standard S-2043 criteria, while simulation predictions with the AAR-1B profiles did not meet Standard S-2043 criteria.

Clockwise (northbound) runs were only done in draft with A-end leading during tests when the cars were equipped with AAR-1B wheel profiles. Only data for CW tests performed in draft with the A-end leading and the car equipped with AAR-2A profiles are shown in this section. Tests with the AAR-2A profile were also performed in buff with A-end leading and in buff and draft with the B-end leading. Data for the other test conditions are shown in the test report.[2]

Table 5. Comparison of test and simulation results for the REV traveling north on the Alps 10-degree curve

Criterion	S-2043 Limiting Value	Alps 10-degree curve, CW			
		Model AAR-2A	Model AAR-1B	Test AAR-2A	Test AAR-1B
Maximum carbody roll angle (degree)	4.0	0.5	0.4	0.4	0.3
Maximum wheel L/V ratio	0.80	0.49	0.64	0.60	0.72
Maximum truck side L/V ratio	0.50	0.26	0.56	0.45	0.50
Minimum vertical wheel load (%)	25%	69%	68%	69%	62%
Peak-to-peak carbody lateral acceleration (g)	0.6	0.13	0.11	0.29	0.21
Maximum carbody lateral acceleration (g)	0.35	0.09	0.08	0.20	0.13
Std dev carbody lateral acceleration (g)	0.13	0.02	0.02	0.05	0.03
Maximum carbody vertical acceleration (g)	0.60	0.15	0.15	0.12	0.13
Maximum vertical suspension deflection (%)	95%	45%	44%	31%	50%

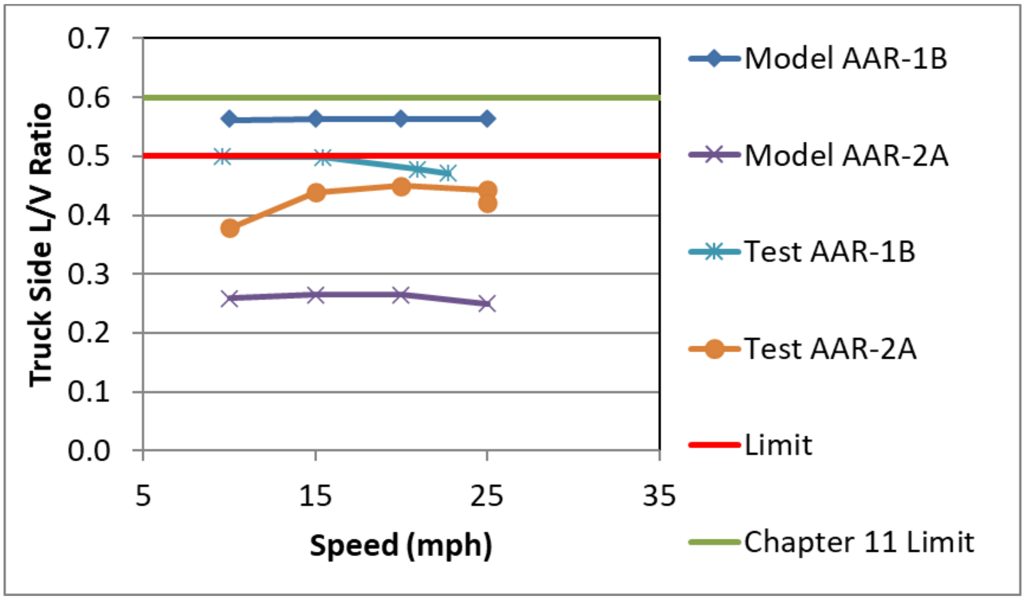

Figure 10. Predicted maximum truck-side L/V ratios for the REV with the minimum test load on the Alps 10-degree curve traveling north compared with actual test results

Table 6 shows the worst-case simulation predictions and test results for the REV on the Alps 10-degree curve traveling south (CCW direction). The model and test configured with the AAR-2A wheel profiles produce much lower maximum wheel and truck-side L/V ratios than the model and test configured with AAR-1B wheel profiles. The actual L/V ratios recorded during the test performed with the AAR-2A profile are higher than those predicted by the model, but both the maximum truck-side L/V ratios remained below the Standard S-2043 limit.

Figure 11 plots the maximum truck-side L/V ratio against the speed for the simulations and tests of the REV traveling south on the Alps 10-degree curve. The plot compares 1) simulations of the car fitted with wheels having idealized AAR-2A profiles, 2) simulations of the car fitted with wheels having idealized AAR-1B profiles, 3) test results of the car fitted with wheels having AAR-1B profiles, and 4) test results of the car fitted with wheels having AAR-2A profiles. The simulation predictions and results with the AAR-2A profiles met the Standard S-2043 criteria, while the simulation predictions and results from tests performed with the AAR-1B profiles did not meet Standard S-2043 criteria.

Counterclockwise (southbound) runs were only done in buff with the B-end leading during tests when the cars were equipped with AAR-1B wheel profiles. Only data for CCW tests performed in buff with the B-end leading and the car equipped with AAR-2A profiles are shown in this section. Tests with the AAR-2A profile were also performed in draft with B-end leading and in buff and draft with the A-end leading. Data for the other test directions is shown in the test report.[2]

Table 6. Comparison of test and simulation results for the REV with the minimum test load traveling south on the Alps 10-degree curve

Criterion	S-2043 Limiting Value	Alps 10-degree curve, CCW			
		Model AAR-2A	Model AAR-1B	Test AAR-2A	Test AAR-1B
Maximum carbody roll angle (degree)	4.0	0.4	0.4	0.4	0.3
Maximum wheel L/V ratio	0.80	0.53	0.80	0.73	0.77
Maximum truck side L/V ratio	0.50	0.26	0.71	0.44	0.56
Minimum vertical wheel load (%)	25%	73%	70%	71%	67%
Peak-to-peak carbody lateral acceleration (g)	0.6	0.14	0.13	0.21	0.18
Maximum carbody lateral acceleration (g)	0.35	0.08	0.08	0.16	0.11
Std dev carbody lateral acceleration (g)	0.13	0.02	0.02	0.04	0.03
Maximum carbody vertical acceleration (g)	0.60	0.16	0.16	0.13	0.14
Maximum vertical suspension deflection (%)	95%	40%	40%	29%	47%

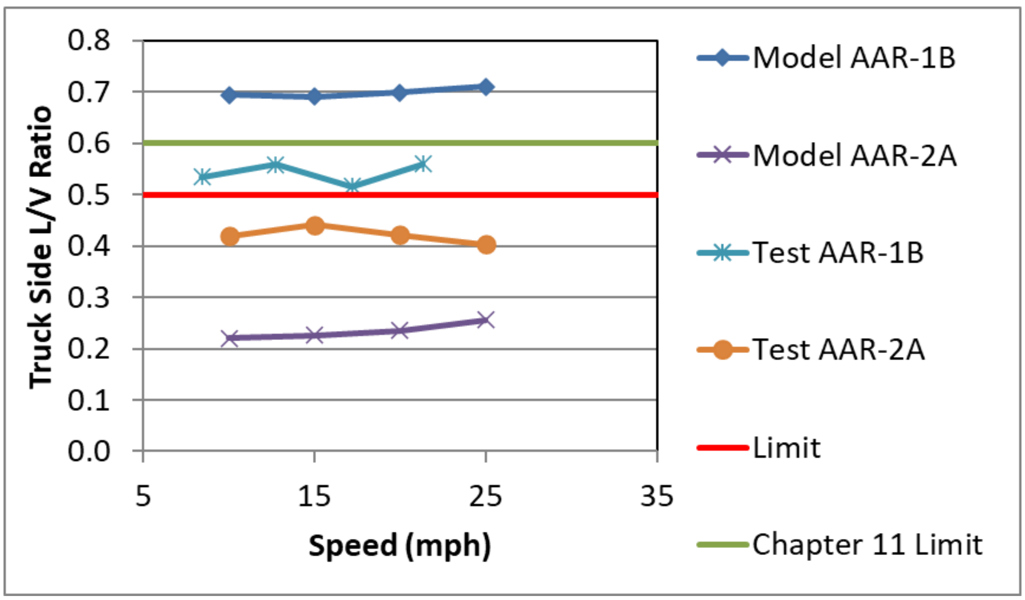

Figure 11. Predicted maximum truck-side L/V ratios for the REV with the minimum test load on the Alps 10-degree curve traveling south compared with actual test results

5.0 SELECT SINGLE CAR REGIMES - ATLAS RAILCAR

Three regimes were modeled for the Atlas railcar: dynamic curving, hunting, and negotiation of a No. 7 crossover. These regimes were selected based on a request (Appendix A) from the AAR Equipment Engineering Committee (EEC) to perform follow-up modeling in areas where either the test or the modeling results of the car equipped with AAR-1B wheel profiles were borderline and performance could become problematic if switching over to AAR-2A profiles caused the performance to degrade significantly.

During the Atlas railcar single car testing program, MxV Rail tested the car with a total of four models of primary suspension pad. The pads are made from chlorosulfonated polyethylene (CSM) and are categorized by the Shore D durometer hardness value. The car arrived with CSM 58 production pads, ASF-Keystone part number 10522A, and these pads were found to have the best balance of curving and hunting performance. All the test results and simulation predictions presented in this report used CSM 58 pads. All three test car types used the CSM 58 10522A pads, and all simulation predictions presented in this report are based on these test cars.

5.1 Dynamic Curving

Simulations of the dynamic curving regime were conducted according to Standard S-2043, paragraph 4.3.9.9 to compare the performance of idealized AAR-1B with idealized AAR-2A wheel profiles. The dynamic curve section is on a 10-degree curve with a 4-inch superelevation. The dynamic curving regime consists of a series of 0.5-inch vertical track deviations at a 39-foot wavelength offset on each rail to input roll motions on the car. There are five deviations on the high rail and six deviations on the low rail. At the same time, the track gage changes from 56.5 inches to 57.5 inches to input lateral motions on the car. The simulations were performed at speeds ranging from 10 mph (approximately 3 inches of cant excess) to 32 mph (approximately 3 inches of cant deficiency) in increments of 2 mph or less. The rail profiles shapes input to the model were based on new, unground, 136-pound rail with 8-inch crown radius. As required by Standard S-2043, the simulations used a coefficient of friction of 0.5 on all wheel-rail contact surfaces. Simulations were conducted for the Empty car, Minimum Test Load, and Maximum Test Load conditions.

5.1.1 Empty

Table 7 shows the worst-case simulation predictions for the empty Atlas railcar in the dynamic curving regime traveling in the CW direction. The overall performance of the two profiles is very similar, but the maximum wheel and truck-side L/V ratios are predicted to be a little lower when using wheels with AAR-1B profiles.

Figure 12 plots the maximum wheel L/V ratio against the simulation speed of the empty Atlas railcar in the CW direction. The plot compares the predicted performance of the Atlas railcar when fitted with wheels having AAR-2A profiles with the predicted performance for the car when fitted with wheels having AAR-1B profiles. The overall performance of the car fitted with AAR-1B wheels is somewhat better than the performance of the car fitted with the AAR-2A profile wheels.

Table 7. Atlas railcar empty dynamic curving CW

Criterion	S-2043 Limiting Value	Model of Dynamic Curving AAR-2A	Model of Dynamic Curving AAR-1B
Maximum carbody roll angle (degree)	4.0	0.3	0.3
Maximum wheel L/V ratio	0.80	0.79	0.76
Maximum truck-side L/V ratio	0.50	0.39	0.37
Minimum vertical wheel load (%)	25%	65%	66%
Peak-to-peak carbody lateral acceleration (g)	1.3	0.1	0.1
Maximum carbody lateral acceleration (g)	0.75	0.07	0.07
Maximum carbody vertical acceleration (g)	0.90	0.06	0.07
Maximum vertical suspension deflection (%)	95%	7%	8%

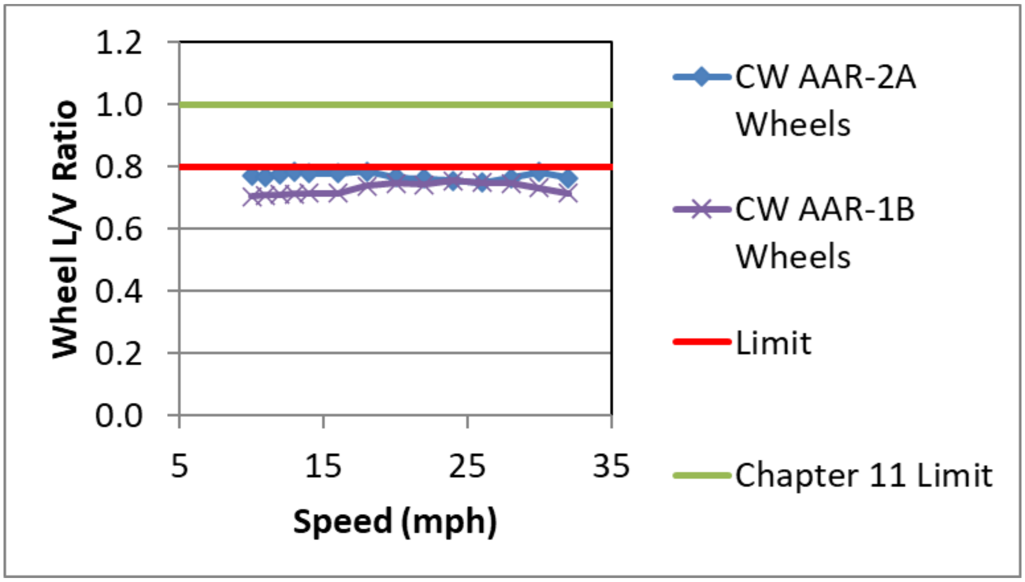

Figure 12. Predicted maximum wheel L/V ratios for the empty Atlas railcar in dynamic curving in the CW direction when equipped with AAR-2A and AAR-1B profile wheels

Table 8 shows the worst-case simulation predictions for the empty Atlas railcar in the dynamic curving regime traveling in the CCW direction. The simulation results also predict a similar performance for the two wheel profiles in the CCW direction, with the maximum wheel and truck-side L/V ratios again being slightly lower for the AAR-1B wheel profiles.

Figure 13 plots the maximum wheel L/V ratio against the speed for simulations of the empty Atlas railcar in the CCW direction. The plot compares the predicted performance of the Atlas railcar when fitted with wheels having AAR-2A profiles with predicted performance for the car when fitted with wheels having AAR-1B profiles. The overall predicted performance is very similar for the two wheel profiles, especially for speeds above 16 mph.

Table 8. Atlas railcar empty dynamic curving CCW

Criterion	S-2043 Limiting Value	Model of Dynamic Curving AAR-2A	Model of Dynamic Curving AAR-1B
Maximum carbody roll angle (degree)	4.0	0.3	0.3
Maximum wheel L/V ratio	0.80	0.76	0.72
Maximum truck-side L/V ratio	0.50	0.38	0.36
Minimum vertical wheel load (%)	25%	65%	66%
Peak-to-peak carbody lateral acceleration (g)	1.3	0.1	0.1
Maximum carbody lateral acceleration (g)	0.75	0.07	0.07
Maximum carbody vertical acceleration (g)	0.90	0.07	0.08
Maximum vertical suspension deflection (%)	95%	8%	8%

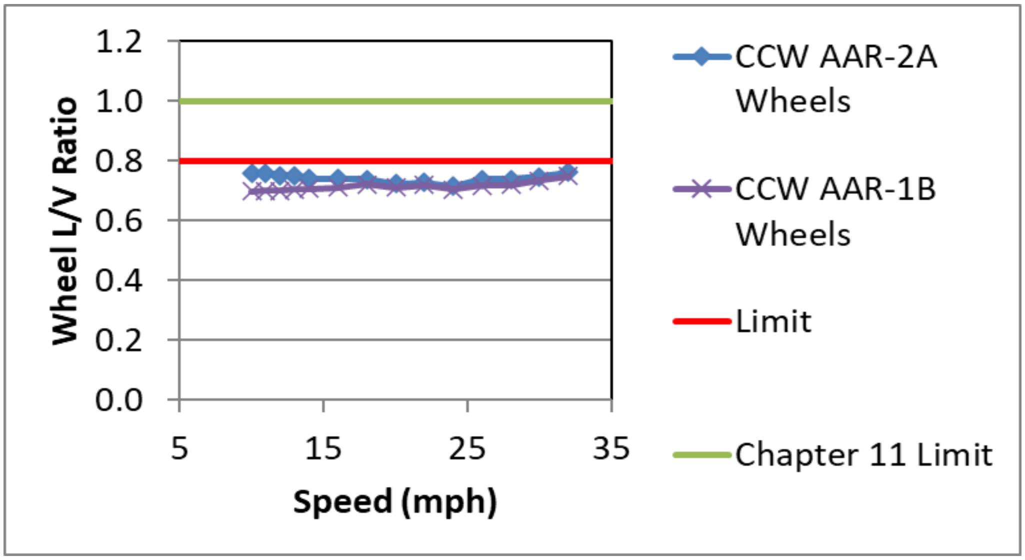

Figure 13. Predicted maximum wheel L/V ratios for the empty Atlas railcar in dynamic curving in the CCW direction when equipped with AAR-2A and AAR-1B profile wheels

The predicted performance of the empty Atlas railcar meets all Standard S-2043 criteria in the dynamic curving regime in both the CW and CCW directions with both AAR-1B and AAR-2A profiles.

5.1.2 Minimum Test Load

Table 9 shows the worst-case simulation predictions for the Atlas railcar with the minimum test load in the dynamic curving regime traveling in the CW direction. When the car is fitted with AAR-1B profiles, the model predicts lower maximum wheel and slightly lower maximum truck-side L/V ratios. Conversely, the model indicates that the AAR-2A profiles will result in a slightly lower carbody roll angle and lower maximum carbody lateral and vertical accelerations. The accelerations and roll angles are well below the Standard S-2043 limit with either profile.

Figure 14 plots the maximum wheel L/V ratio against the simulation speed of the Atlas railcar with the minimum test load in the CW direction. The plot compares the predicted performance of the Atlas railcar when fitted with wheels having AAR-2A profiles with the predicted performance for the car when fitted with wheels having AAR-1B profiles. The simulations predict better performance with the AAR-1B wheel profile.

Table 9. Atlas railcar minimum test load dynamic curving CW

Criterion	S-2043 Limiting Value	Model of Dynamic Curving AAR-2A	Model of Dynamic Curving AAR-1B
Maximum carbody roll angle (degree)	4.0	0.8	1.0
Maximum wheel L/V ratio	0.80	0.75	0.70
Maximum truck-side L/V ratio	0.50	0.37	0.35
Minimum vertical wheel load (%)	25%	53%	53%
Peak-to-peak carbody lateral acceleration (g)	1.3	0.2	0.2
Maximum carbody lateral acceleration (g)	0.75	0.10	0.14
Maximum carbody vertical acceleration (g)	0.90	0.06	0.11
Maximum vertical suspension deflection (%)	95%	11%	22%

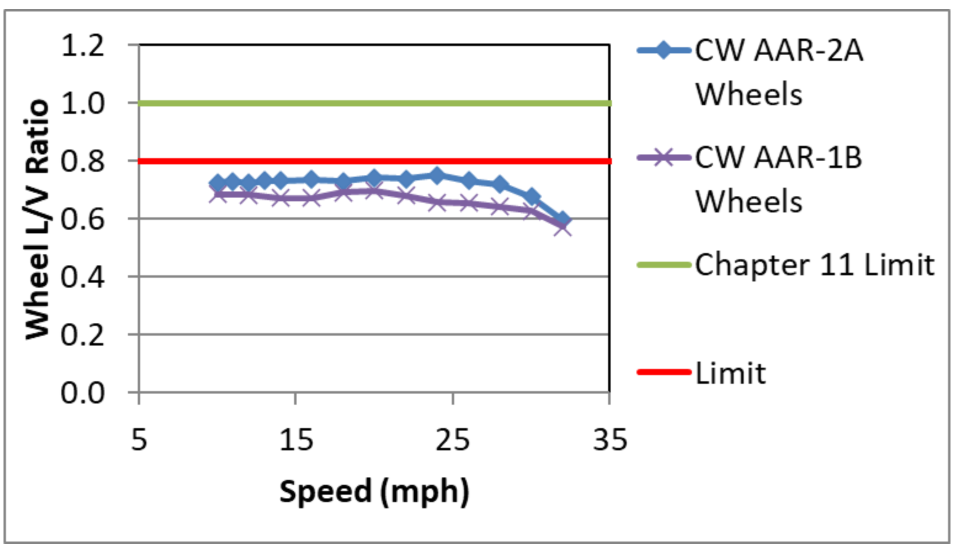

Figure 14. Predicted maximum wheel L/V ratios for the Atlas railcar with the minimum test load in dynamic curving in the CW direction when equipped with AAR-2A and AAR-1B profile wheels

Table 10 shows the worst-case simulation predictions for the Atlas railcar with the minimum test load traveling in the CCW direction in the dynamic curving regime. The simulations indicate that AAR-1B profiles produce a lower maximum truck-side L/V ratio. The model also predicts that the AAR-2A profiles produce lower maximum carbody lateral and vertical accelerations. The accelerations do not approach the Standard S-2043 limit with either profile.

Figure 15 plots the maximum wheel L/V ratio against the speed for simulations of the Atlas railcar with the minimum test load in the CCW direction. The plot compares the predicted performance of the Atlas railcar when fitted with wheels having AAR-2A profiles with the predicted performance for the car when fitted with wheels having AAR-1B profiles. The simulations predict very similar performance for the two profiles.

Table 10. Atlas railcar minimum test load dynamic curving CCW

Criterion	S-2043 Limiting Value	Model of Dynamic Curving AAR-2A	Model of Dynamic Curving AAR-1B
Maximum carbody roll angle (degree)	4.0	0.9	1.0
Maximum wheel L/V ratio	0.80	0.71	0.71
Maximum truck-side L/V ratio	0.50	0.39	0.35
Minimum vertical wheel load (%)	25%	54%	55%
Peak-to-peak carbody lateral acceleration (g)	1.3	0.2	0.2
Maximum carbody lateral acceleration (g)	0.75	0.10	0.16
Maximum carbody vertical acceleration (g)	0.90	0.07	0.11
Maximum vertical suspension deflection (%)	95%	11%	23%

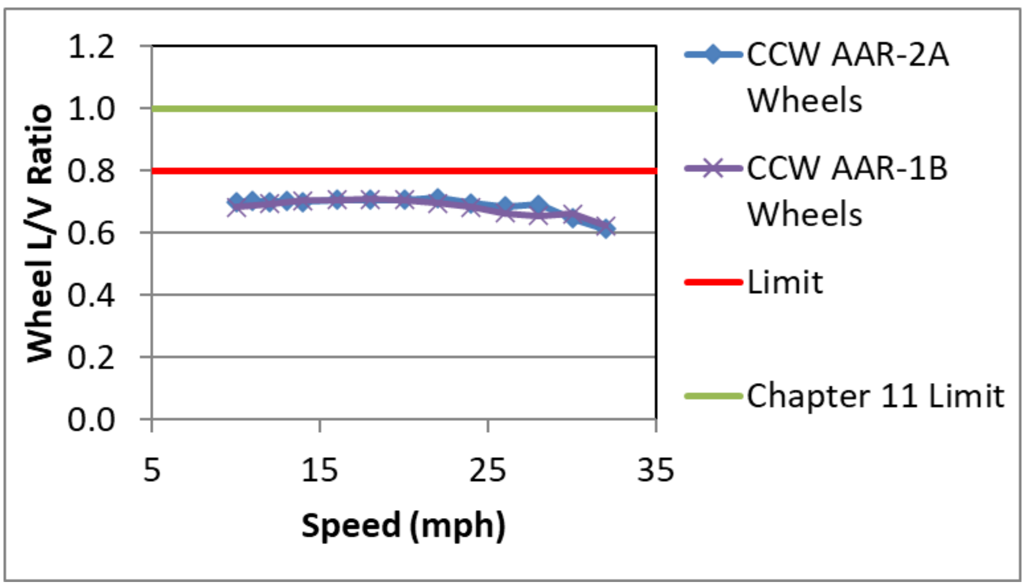

Figure 15. Predicted maximum wheel L/V ratios for the Atlas railcar with the minimum test load in dynamic curving in the CCW direction when equipped with AAR-2A and AAR-1B profile wheels

The predicted performance of the Atlas railcar with the minimum test load meets all Standard S-2043 criteria in the dynamic curving regime in both the CW and CCW directions with both AAR-1B and AAR-2A profiles.

5.1.3 Maximum Test Load

Table 11 shows the worst-case simulation predictions for the Atlas railcar with the maximum test load in the dynamic curving regime traveling in the CW direction. The model predicts lower maximum wheel and truck-side L/V ratios with AAR-1B profiles. The model also predicts lower maximum carbody lateral and much lower maximum carbody vertical accelerations using the AAR-2A profiles, and the accelerations do not approach the Standard S-2043 limit with either profile.

Figure 16 plots the maximum wheel L/V ratio against the speed for simulations of the Atlas railcar with the maximum test load in the CW direction. The plot compares the predicted performance of the Atlas railcar when fitted with wheels having AAR-2A profiles with the predicted performance for the car when fitted with wheels having AAR-1B profiles. The simulations predict better performance when the car is configured with wheels having AAR-1B profiles for speeds below 28 mph.

Table 11. Atlas railcar maximum test load dynamic curving CW

Criterion	S-2043 Limiting Value	Model of Dynamic Curving AAR-2A	Model of Dynamic Curving AAR-1B
Maximum carbody roll angle (degree)	4.0	0.9	1.0
Maximum wheel L/V ratio	0.80	0.75	0.61
Maximum truck-side L/V ratio	0.50	0.35	0.30
Minimum vertical wheel load (%)	25%	55%	56%
Peak-to-peak carbody lateral acceleration (g)	1.3	0.10	0.11
Maximum carbody lateral acceleration (g)	0.75	0.06	0.12
Maximum carbody vertical acceleration (g)	0.90	0.08	0.25
Maximum vertical suspension deflection (%)	95%	28%	48%

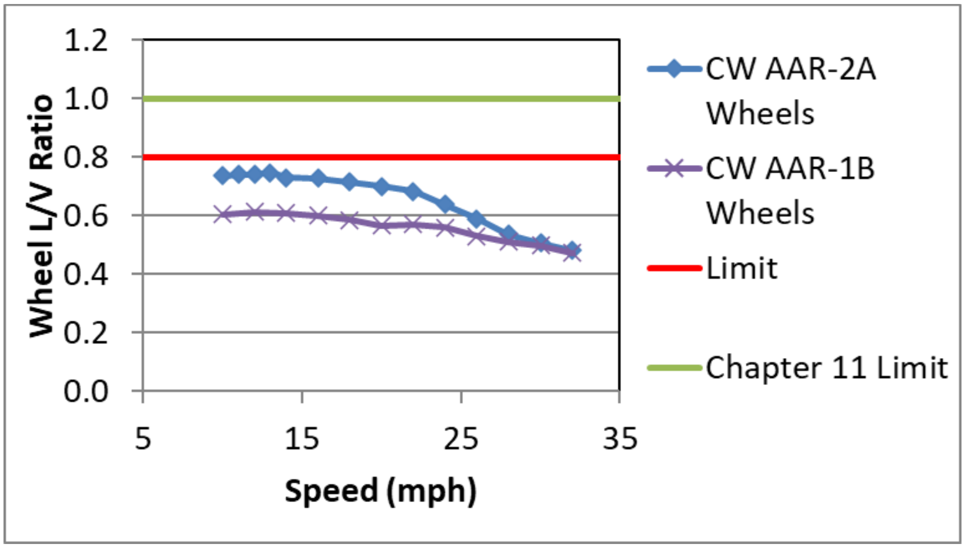

Figure 16. Predicted maximum wheel L/V ratios for the Atlas railcar with the maximum test load in dynamic curving in the CW direction when equipped with AAR-2A and AAR-1B profile wheels

Table 12 shows the worst-case simulation predictions for the Atlas railcar with the maximum test load in the dynamic curving regime traveling in the CCW direction. Similar to the CW direction, the model predicts somewhat lower maximum wheel and lower maximum truck-side L/V ratios with AAR-1B profiles while also predicting that the maximum carbody lateral and vertical accelerations will be lower using the AAR-2A profiles (the accelerations do not approach the Standard S-2043 limit with either profile).

Figure 17 plots the maximum wheel L/V ratio against the speed for simulations of the Atlas railcar with the maximum test load in the CCW direction. The plot compares the predicted performance of the Atlas railcar when fitted with wheels having AAR-2A profiles with the predicted performance for the car when fitted with wheels having AAR-1B profiles. The predicted performance of the car is similar for the two wheel profiles; however, the AAR-1B profile does have a little better performance for speeds above 14 mph.

Table 12. Atlas railcar maximum test load dynamic curving CCW

Criterion	S-2043 Limiting Value	Model of Dynamic Curving AAR-2A	Model of Dynamic Curving AAR-1B
Maximum carbody roll angle (degree)	4.0	0.9	1.0
Maximum wheel L/V ratio	0.80	0.71	0.68
Maximum truck-side L/V ratio	0.50	0.34	0.29
Minimum vertical wheel load (%)	25%	55%	55%
Peak-to-peak carbody lateral acceleration (g)	1.3	0.1	0.1
Maximum carbody lateral acceleration (g)	0.75	0.07	0.12
Maximum carbody vertical acceleration (g)	0.90	0.09	0.25
Maximum vertical suspension deflection (%)	95%	30%	49%

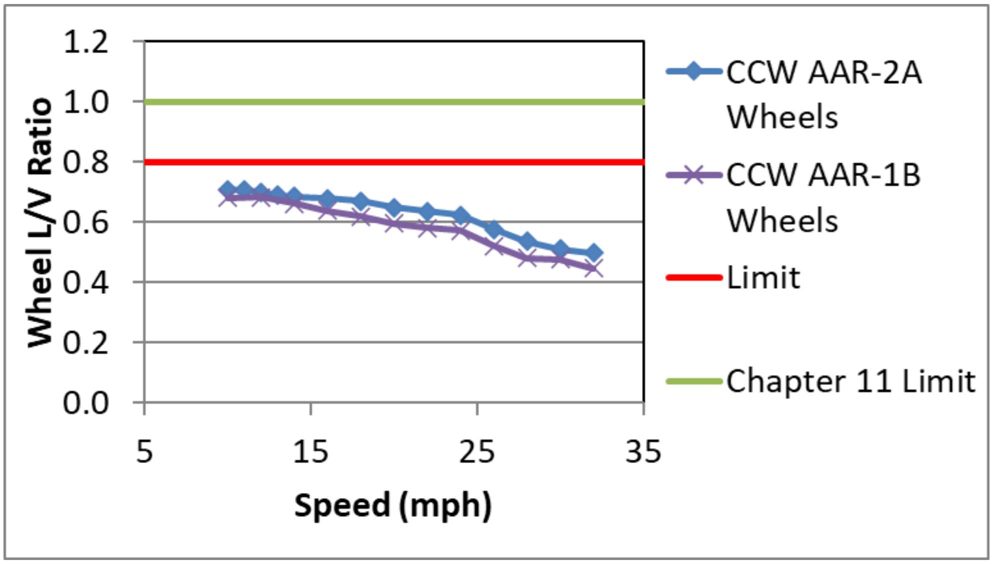

Figure 17. Predicted Maximum wheel L/V ratios for the Atlas railcar with the maximum test load in dynamic curving in the CCW direction when equipped with AAR-2A and AAR-1B profile wheels

The predicted performance of the Atlas railcar with the maximum test load meets all Standard S-2043 criteria in the dynamic curving regime in both the CW and CCW directions with both AAR-1B and AAR-2A profiles.

5.2 Hunting

Simulations of the hunting regime were conducted according to Standard S-2043, paragraph 4.3.11.3.1 to compare the performance of the idealized KR with the idealized AAR-2A wheel profiles. The KR profile wheels were chosen for the hunting simulations instead of AAR-1B profile wheels due to the fact that the KR profile wheels represent a slightly worn profile, similar to the AAR-1B after 50,000–100,000 miles of wear, that is more likely to cause hunting in vehicles that have tendency for lateral instability. Prior to the introduction of the AAR-2A wheel in 2020, Standard S-2043 required KR wheels for hunting tests and simulations. A substitute "worn profile" is not needed for the AAR-2A because the shape of the AAR-2A profile does not change much during initial wear. Since the adoption of the AAR-2A profile in 2020, the AAR-1B and the KR profile have been removed from Chapter 11. The simulations used inputs from the measured track geometry of the test site, a 5,500-foot section of tangent track on the Railroad Test Track (RTT) at the Transportation Technology Center (TTC) in Pueblo, CO. The simulations were run at speeds between 30 and 80 mph in 5 mph increments (the minimum and maximum test loads with KR wheels were only simulated up to 75 mph). Simulations were conducted for the Empty car, Minimum Test Load, and Maximum Test Load conditions.

5.2.1 Empty

Table 13 shows the worst-case simulation predictions for the empty Atlas railcar in the hunting regime. The model predicts that the KR profiles maintain a higher minimum vertical wheel load and a somewhat lower maximum wheel L/V ratio than the AAR-2A profiles. The maximum carbody vertical acceleration is also predicted to be slightly lower for the KR profiles. Conversely, the AAR-2A wheel profiles are predicted to maintain a somewhat lower maximum carbody lateral acceleration and maximum standard deviation of the carbody lateral acceleration than the KR profiles.

Figure 18 shows the maximum standard deviation of the carbody lateral acceleration calculated over a sliding 1,000-foot window plotted against speed for the empty Atlas railcar. The plot compares the predicted performance of the Atlas railcar when fitted with wheels having AAR-2A profiles with the predicted performance for the car when fitted with wheels having KR profiles. The model predicts that the relative performance of the two profiles varies over the range of speeds simulated. Overall, the predicted lateral stability of the car fitted with the AAR-2A profile wheels is equivalent to or better than what is predicted for the car fitted with KR profile wheels with the exception of 60 mph, where the relative performance of the profiles reverses.

Table 13. Atlas railcar empty hunting

Criterion	S-2043 Limiting Value	Model of Hunting AAR-2A	Model of Hunting KR
Maximum carbody roll angle (degree)	4.0	0.7	0.8
Maximum wheel L/V ratio	0.80	0.64	0.62
Maximum truck-side L/V ratio	0.50	0.40	0.39
Minimum vertical wheel load (%)	25%	39%	45%
Peak-to-peak carbody lateral acceleration (g)	1.3	0.4	0.4
Maximum carbody lateral acceleration (g)	0.75	0.20	0.22
Std dev carbody lateral acceleration (g)	0.13	0.08	0.10
Maximum carbody vertical acceleration (g)	0.90	0.27	0.24
Maximum vertical suspension deflection (%)	95%	14%	15%

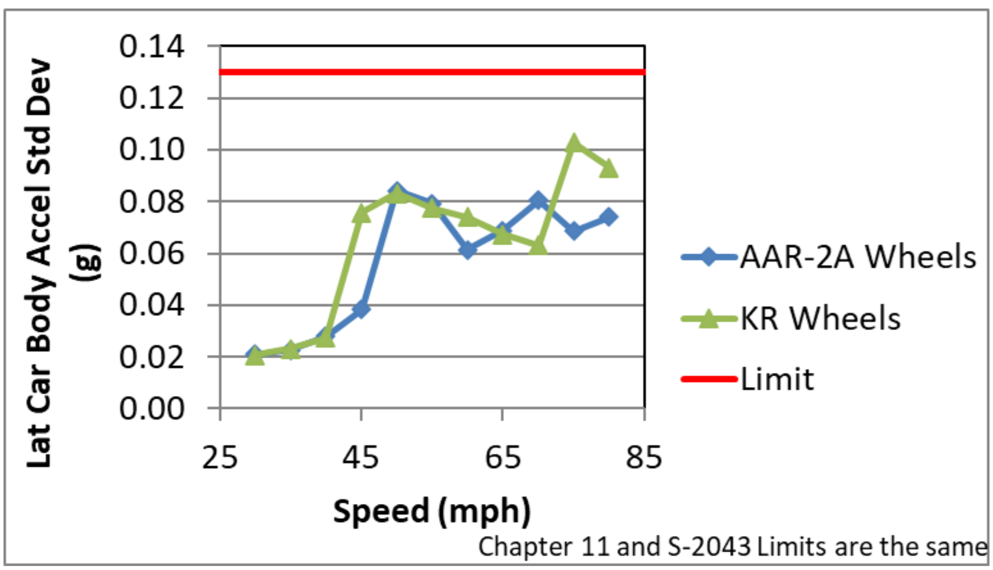

Figure 18. Predicted maximum standard deviation of the carbody lateral acceleration for the empty Atlas railcar in hunting when equipped with AAR-2A and KR profile wheels

The predicted performance of the empty Atlas railcar meets all Standard S-2043 criteria in the hunting regime with both AAR-2A and the KR profile wheels.

5.2.2 Minimum Test Load

Table 14 shows the worst-case simulation predictions for the Atlas railcar with the minimum test load in the hunting regime. The model predicts that the AAR-2A profiles will produce lower maximum wheel and truck-side L/V ratios than the KR profiles. The model also predicts a lower maximum carbody lateral acceleration and lower maximum peak-to-peak and standard deviation of the carbody lateral accelerations with AAR-2A profiles. The maximum standard deviation of the carbody lateral acceleration for the model equipped with KR wheels is 0.14, which exceeds the limit set by Standard S-2043 (and Chapter 11) of 0.13. The model predictions do meet Standard S-2043 for all other criteria when configured with KR wheels.

Figure 19 shows the maximum standard deviation of the lateral carbody acceleration calculated over a sliding 1,000-foot window plotted against the speed for the Atlas railcar with the minimum test load. The plot compares the predicted performance of the Atlas railcar when fitted with wheels having AAR-2A profiles with the predicted performance for the car when fitted with wheels having KR profiles. The predicted lateral stability of the car is very similar for both profiles up to 55 mph. After this speed, the AAR-2A profiles are significantly better than the KR profiles. The car will be limited to 50 mph or less by AAR Operating Transportation (OT) circular OT-55[7] when in high-level radioactive material (HLRM) service.

Table 14. Atlas railcar minimum test load hunting

Criterion	S-2043 Limiting Value	Model of Hunting AAR-2A	Model of Hunting Curving KR
Maximum carbody roll angle (degree)	4.0	0.3	0.3
Maximum wheel L/V ratio	0.80	0.23	0.30
Maximum truck-side L/V ratio	0.50	0.14	0.18
Minimum vertical wheel load (%)	25%	69%	69%
Peak-to-peak carbody lateral acceleration (g)	1.3	0.4	0.6
Maximum carbody lateral acceleration (g)	0.75	0.21	0.30
Std dev carbody lateral acceleration (g)	0.13	0.07	0.14
Maximum carbody vertical acceleration (g)	0.90	0.20	0.18
Maximum vertical suspension deflection (%)	95%	8%	17%

Figure 19. Predicted maximum standard deviation of the carbody lateral acceleration for the Atlas railcar with the minimum test load in hunting when equipped with AAR-2A and KR profile wheels

The predicted performance of the Atlas railcar with the minimum test load met all Standard S-2043 criteria in the hunting regime with AAR-2A wheel profiles. The predicted performance with KR profiles does not meet Standard S-2043 requirements for the standard deviation of the carbody lateral acceleration but does meet Standard S-2043 requirements for all other performance measures.

5.2.3 *Maximum Test Load*

Table 15 shows the worst-case simulation predictions for the Atlas railcar with the maximum test load in the hunting regime. The model predicts that the KR profiles will maintain lower maximum wheel and truck-side L/V ratios and a slightly higher minimum vertical wheel load than the AAR-2A profiles. The model also predicts a lower maximum carbody lateral acceleration and a lower maximum standard deviation of the carbody lateral acceleration with KR profiles. Conversely, the AAR-2A wheel profiles are predicted to maintain a lower maximum carbody vertical acceleration than the KR profiles.

Figure 20 plots the maximum standard deviation of the lateral carbody acceleration calculated over a sliding 1,000-foot window plotted against the speed for the Atlas railcar with the maximum test load. The plot compares the predicted performance of the Atlas railcar when fitted with wheels having AAR-2A profiles with the predicted performance for the car when fitted with wheels having KR profiles. The model indicates similar performance for both profiles up to 70 mph, after which the KR profiles perform much better.

Table 15. Atlas railcar maximum test load hunting

Criterion	S-2043 Limiting Value	Model of Hunting AAR-2A	Model of Hunting KR
Maximum carbody roll angle (degree)	4.0	0.4	0.3
Maximum wheel L/V ratio	0.80	0.14	0.09
Maximum truck-side L/V ratio	0.50	0.11	0.08
Minimum vertical wheel load (%)	25%	79%	81%
Peak-to-peak carbody lateral acceleration (g)	1.3	0.4	0.3
Maximum carbody lateral acceleration (g)	0.75	0.22	0.15
Std dev carbody lateral acceleration (g)	0.13	0.08	0.04
Maximum carbody vertical acceleration (g)	0.90	0.29	0.31
Maximum vertical suspension deflection (%)	95%	17%	81%

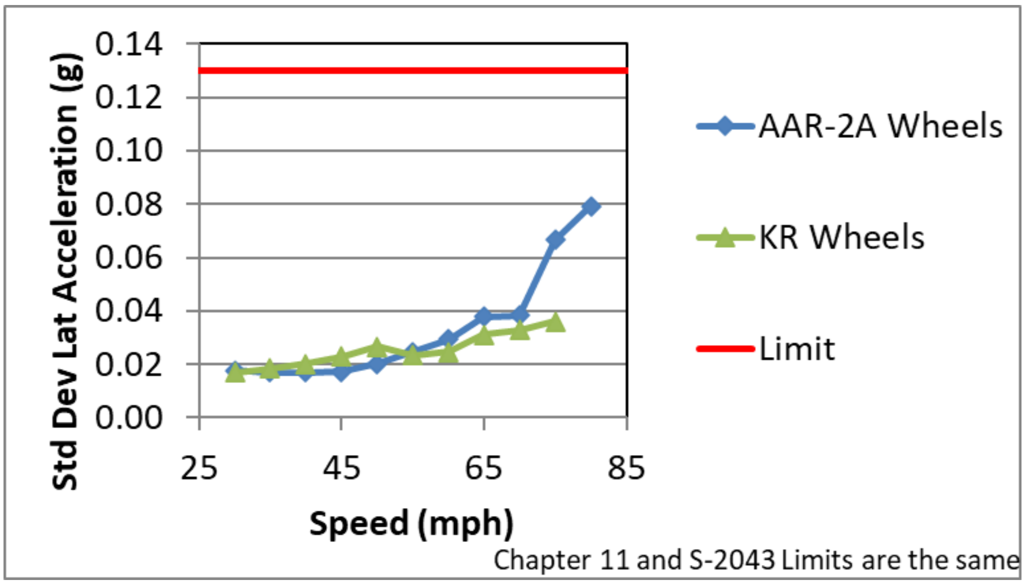

Figure 20. Predicted maximum standard deviation of the carbody lateral acceleration for the Atlas railcar with the maximum test load in hunting when equipped with AAR-2A and KR profile wheels

The predicted performance of the Atlas railcar with the maximum test load meets all Standard S-2043 criteria in the hunting regime with both AAR-2A and KR profiles, but the overall performance of the KR profiles is better above 70 mph. The car will be limited to 50 mph or less by AAR Operating Transportation (OT) circular OT-55[7] when in HLRM service.

5.3 No. 7 Crossover

The simulations for the No. 7 crossover were conducted according to Standard S-2043, paragraph 4.3.11.7 to compare the performance of idealized AAR-1B with the performance of idealized AAR-2A wheel profiles. The simulations were performed using ideal track inputs that included track geometry deviations due to the switch riser, the turnout entry angles, and the closure curves. The changing rail geometry was modeled based on the unworn shapes of the components. The nominal clearance of the guardrails at the frogs were modeled as well. The simulations were run at speeds from 3 to 15 mph in 2 mph increments. Simulations were conducted for the Minimum and Maximum Test Load conditions.

5.3.1 Minimum Test Load

Table 16 presents the worst-case simulation predictions for the Atlas railcar with the minimum test load and the A-end leading in a No. 7 crossover. The model predicts that the AAR-2A profiles will produce a lower maximum wheel L/V ratio than the AAR-1B profiles. However, the model also predicts a slightly higher maximum truck-side L/V ratio and peak-to-peak lateral carbody acceleration with the AAR-2A profiles. The maximum truck-side L/V ratio for the model equipped with AAR-2A wheels is 0.51, which exceeds the Standard S-2043 limit of 0.50, but meets the Chapter 11 limit of 0.6. The model predictions do meet Standard S-2043 for all other criteria when configured with AAR-2A wheels.

Figure 21 plots the maximum truck-side L/V ratio against speed for simulations of the Atlas railcar with the minimum test load and the A-end leading. The plot compares the predicted performance of the Atlas railcar when fitted with wheels having AAR-2A profiles with the predicted performance for the car when fitted with wheels having AAR-1B profiles. The predicted performance of the car is similar for the two wheel profiles. However, while the maximum truck-side L/V ratios for the AAR-2A profiles are at or slightly above the Standard S-2043 limit at all speeds, the maximums predicted for the AAR-1B profiles remain just below the limit.

Table 16. Atlas railcar minimum test load No. 7 crossover A-end leading

Criterion	S-2043 Limiting Value	Model of No. 7 Crossover A-Lead AAR-2A	Model of No. 7 Crossover A-Lead AAR-1B
Maximum carbody roll angle (degree)	4.0	0.1	0.1
Maximum wheel L/V ratio	0.80	0.63	0.76
Maximum truck-side L/V ratio	0.50	0.51	0.49
Minimum vertical wheel load (%)	25%	40%	41%
Peak-to-peak carbody lateral acceleration (g)	1.3	0.3	0.27
Maximum carbody lateral acceleration (g)	0.75	0.14	0.14
Maximum carbody vertical acceleration (g)	0.90	0.14	0.13
Maximum vertical suspension deflection (%)	95%	20%	27%

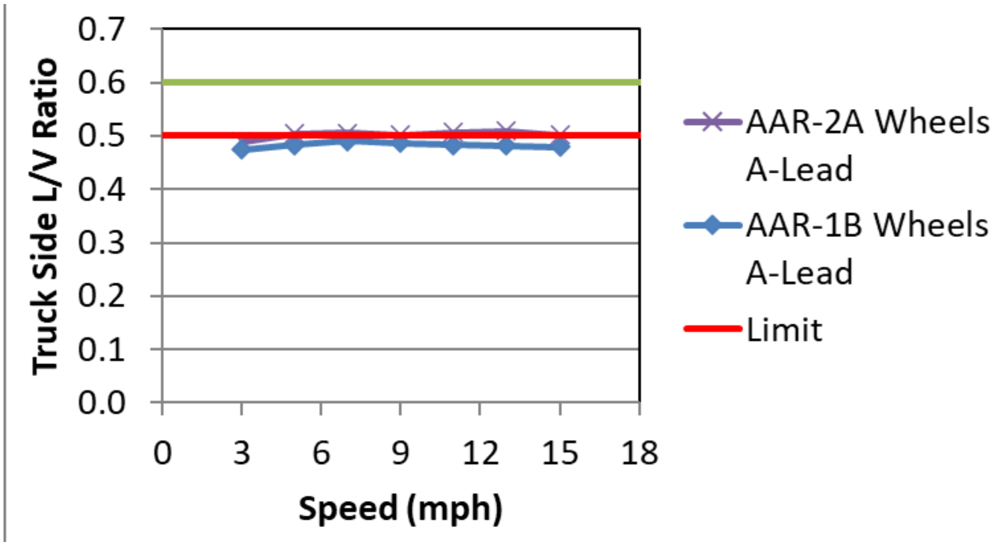

Figure 21. Predicted maximum truck-side L/V ratios for the Atlas railcar with the minimum test load A-end leading in a No. 7 crossover when equipped with AAR-2A and AAR-1B profile wheels

Table 17 presents the worst-case simulation predictions for the Atlas railcar with the minimum test load and the B-end leading in a No. 7 crossover. The model predicts that the AAR-2A profiles produce a slightly lower maximum wheel L/V ratio than the AAR-1B profiles. However, the model also predicts that the AAR-1B profiles will produce a slightly lower maximum truck-side L/V ratio and a slightly higher minimum wheel load. The maximum truck-side L/V ratio for the model equipped with AAR-2A wheels is 0.51, which exceeds the limit of 0.50 set by Standard S-2043 but meets the Chapter 11 limit of 0.6. The model predictions do meet Standard S-2043 for all other criteria when configured with AAR-2A wheels.

Figure 22 plots the maximum truck-side L/V ratio against speed for simulations of the Atlas railcar with the minimum test load and the B-end leading. The results for the B-end leading are very similar to those for the A-end leading. The maximum truck-side L/V ratios for the AAR-2A profiles are at or slightly above the Standard S-2043 limit at all speeds, and the maximums predicted for the AAR-1B profiles remain just below the limit.

Table 17. Atlas railcar minimum test load No. 7 crossover B-end leading

Criterion	S-2043 Limiting Value	Model of No. 7 Crossover B-Lead AAR-2A	Model of No. 7 Crossover B-Lead AAR-1B
Maximum carbody roll angle (degree)	4.0	0.1	0.1
Maximum wheel L/V	0.80	0.63	0.65
Maximum truck-side L/V ratio	0.50	0.51	0.49
Minimum vertical wheel load (%)	25%	40%	42%
Peak-to-peak carbody lateral acceleration (g)	1.3	0.3	0.3
Maximum carbody lateral acceleration (g)	0.75	0.15	0.14
Maximum carbody vertical acceleration (g)	0.90	0.14	0.15
Maximum vertical suspension deflection (%)	95%	21%	28%

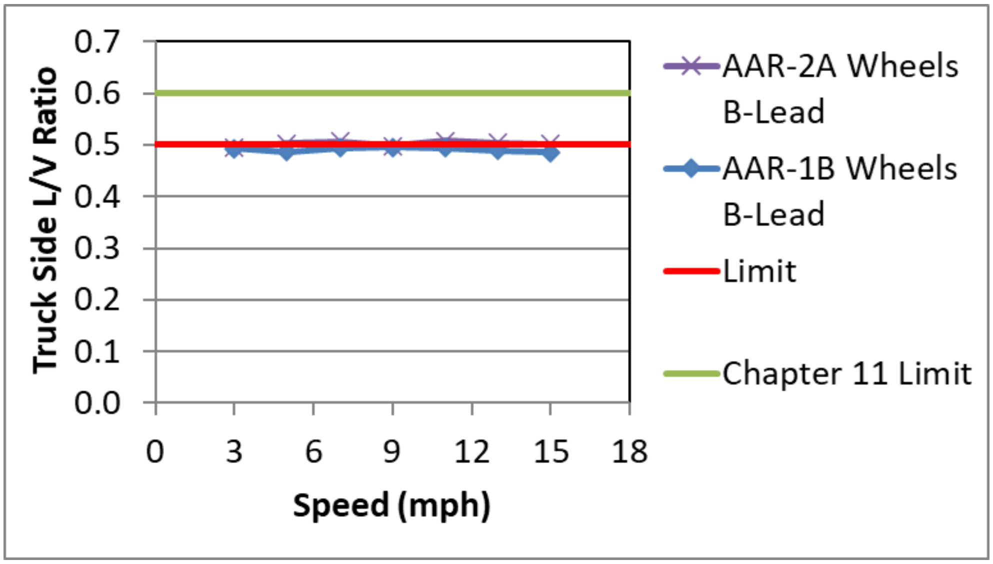

Figure 22. Predicted maximum truck-side L/V ratios for the Atlas railcar with the minimum test load B-end leading in a No. 7 crossover when equipped with AAR-2A and AAR-1B profile wheels

The predicted performance of the Atlas railcar with the minimum test load through a No. 7 Crossover meets all Standard S-2043 criteria with AAR-1B wheel profiles with both the A-end and B-end leading. The predicted performance with AAR-2A wheel profiles does not meet Standard S-2043 requirements for the maximum truck-side L/V ratio with either the A-end or the B-end leading, but it does meet all other Standard S-2043 criteria with both the A-end and B-end leading.

5.3.2 Maximum Test Load

Table 18 shows the worst-case simulation predictions for the Atlas railcar with the maximum test load and the A-end leading in a No. 7 crossover. The model predicts that the AAR-2A and AAR-1B profiles will have very similar overall performance.

Figure 23 shows the maximum truck-side L/V ratio plotted against the speed for simulations of the Atlas railcar with the maximum test load and the A-end leading. The plots of the two profiles basically fall on top of each other and only show an obvious separation at the maximum speed simulated (15 mph).

Table 18. Atlas railcar maximum test load No. 7 crossover A-end leading

Criterion	S-2043 Limiting Value	Model of No. 7 Crossover AAR-2A	Model of No. 7 Crossover AAR-1B
Maximum carbody roll angle (degree)	4.0	0.3	0.3
Maximum wheel L/V ratio	0.80	0.60	0.61
Maximum truck-side L/V ratio	0.50	0.49	0.48
Minimum vertical wheel load (%)	25%	70%	71%
Peak-to-peak carbody lateral acceleration (g)	1.3	0.2	0.2
Maximum carbody lateral acceleration (g)	0.75	0.11	0.11
Maximum carbody vertical acceleration (g)	0.90	0.08	0.09
Maximum vertical suspension deflection (%)	95%	27%	37%

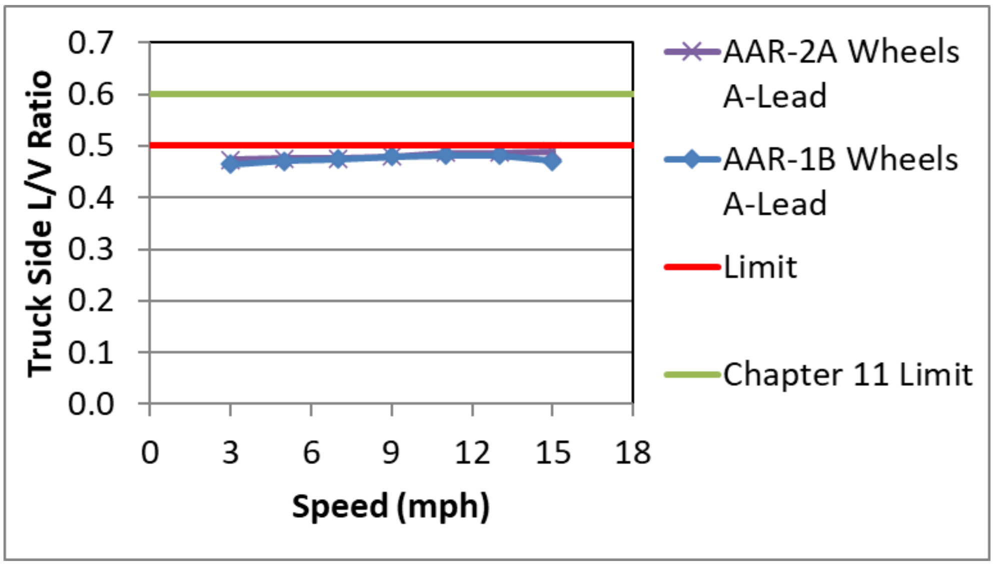

Figure 23. Predicted maximum truck-side L/V ratios for the Atlas railcar with the maximum test load a-end leading in a No. 7 crossover when equipped with AAR-2A and AAR-1B profile wheels

Table 19 shows the worst-case simulation predictions for the Atlas railcar with the maximum test load and the B-end leading in a No. 7 crossover. The model indicates that the AAR-2A wheel profiles will produce a lower maximum wheel L/V ratio, but overall, the two profiles have very similar performance.

Figure 24 plots the maximum truck-side L/V ratio against the speed for simulations of the Atlas railcar with the maximum test load and the B-end leading. The plots of the two profiles basically fall on top of each other over the whole range of speeds simulated.

Table 19. Atlas railcar maximum test load No. 7 crossover B-end leading

Criterion	S-2043 Limiting Value	Model of No. 7 Crossover AAR-2A	Model of No. 7 Crossover AAR-1B
Maximum carbody roll angle (degree)	4.0	0.3	0.3
Maximum wheel L/V ratio	0.80	0.58	0.63
Maximum truck-side L/V ratio	0.50	0.48	0.48
Minimum vertical wheel load (%)	25%	70%	69%
Peak-to-peak carbody lateral acceleration (g)	1.3	0.2	0.2
Maximum carbody lateral acceleration (g)	0.75	0.11	0.11
Maximum carbody vertical acceleration (g)	0.90	0.08	0.09
Maximum vertical suspension deflection (%)	95%	28%	37%

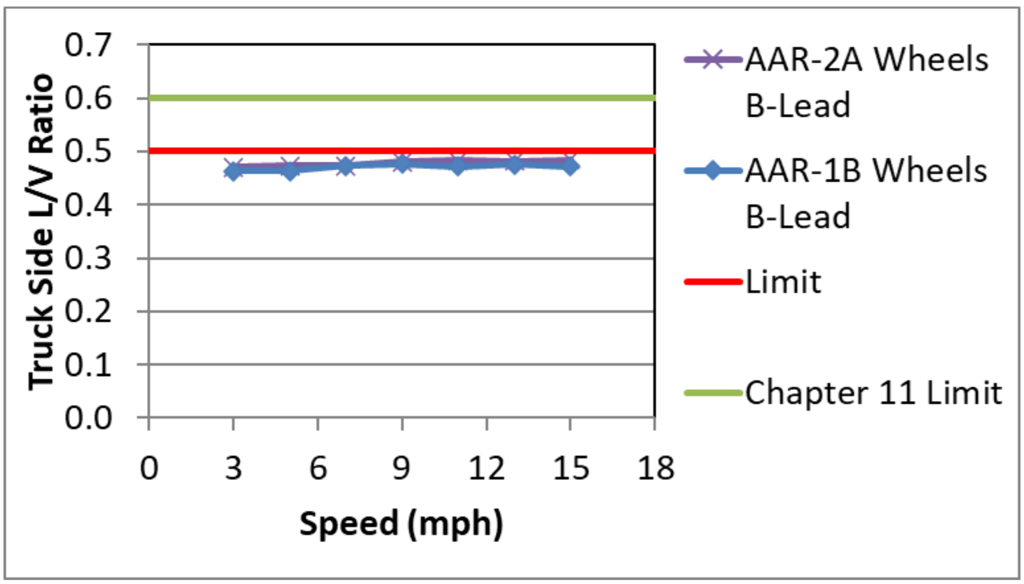

Figure 24. Predicted maximum truck-side L/V ratios for the Atlas railcar with the maximum test load B-end leading in a No. 7 crossover when equipped with AAR-2A and AAR-1B profile wheels

The predicted performance of the Atlas railcar with the maximum test load through a No. 7 crossover meets all Standard S-2043 criteria with both AAR-1B and AAR-2A wheel profiles with both the A-end and B-end leading.

6.0 SELECT SINGLE CAR REGIMES -- REV

The following six regimes were modeled for the REV: dynamic curving, hunting, yaw and sway, curving with a single bump/dip, negotiation of a No. 7 crossover, and ride quality. These regimes were selected based on a request from the EEC (Appendix A) to perform follow-up modeling in areas where either the test or the modeling results of the car equipped with AAR-1B wheel profiles were borderline and performance could become problematic if switching over to AAR-2A profiles caused the performance to degrade significantly.

6.1 Dynamic Curving

Simulations of the dynamic curving regime were conducted according to Standard S-2043, paragraph 4.3.9.9 to compare the performance of idealized AAR-1B wheel profiles with idealized AAR-2A wheel profiles. The simulations were performed at speeds ranging from 10 mph to 32 mph in increments of 2 mph or less.

Table 20 presents the worst-case simulation predictions for the REV in the dynamic curving regime traveling in the CW direction. The model predicts lower maximum wheel and truck-side L/V ratios and a somewhat higher minimum vertical wheel load with the AAR-2A wheel profiles. The model also predicts a slightly lower maximum peak-to-peak carbody lateral acceleration, a lower maximum carbody lateral acceleration, and a slightly lower maximum carbody vertical acceleration using the AAR-2A profiles.

Figure 25 plots the maximum wheel L/V ratio against the speed for simulations of the REV in the CW direction. The plot compares the predicted performance of the REV when fitted with wheels having AAR-2A profiles with the predicted performance for the car when fitted with wheels having AAR-1B profiles. The two profiles have similar performance at speeds of 10 to 12 mph, but after 13 mph, the model predicts much better performance from the AAR-2A profiles.

Table 20. REV dynamic curving CW

Criterion	S-2043 Limiting Value	Model AAR-2A	Model AAR-1B
Maximum carbody roll angle (degree)	4.0	1.3	1.3
Maximum wheel L/V ratio	0.80	0.63	0.68
Maximum truck-side L/V ratio	0.50	0.22	0.30
Minimum vertical wheel load (%)	25%	59%	56%
Peak-to-peak carbody lateral acceleration (g)	0.6	0.27	0.29
Maximum carbody lateral acceleration (g)	0.35	0.16	0.24
Maximum carbody vertical acceleration (g)	0.60	0.10	0.12
Maximum vertical suspension deflection (%)	95%	25%	29%

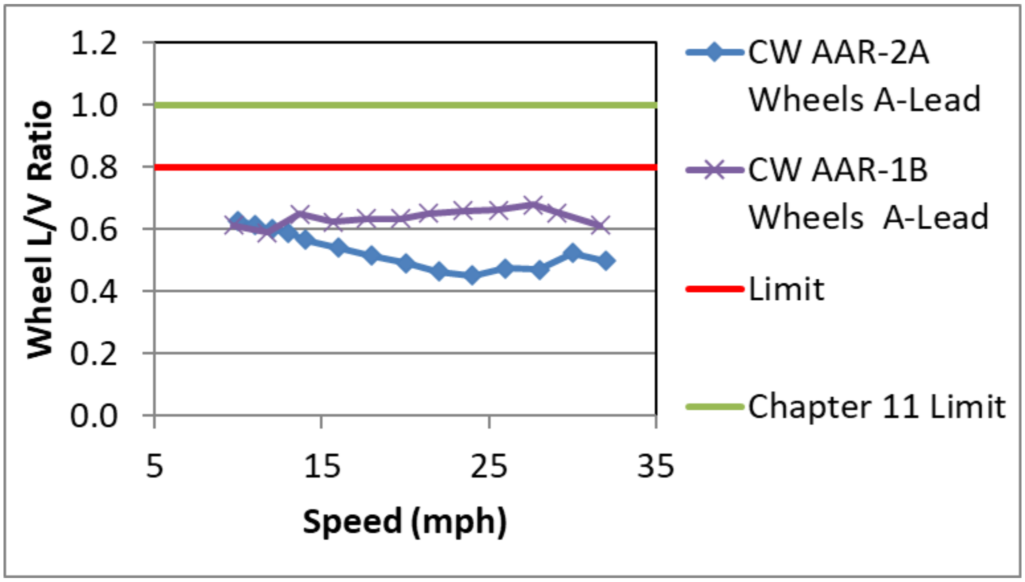

Figure 25. Predicted maximum wheel L/V ratios for the REV in dynamic curving in the CW direction when equipped with AAR-2A and AAR-1B profile wheels

Table 21 shows the worst-case simulation predictions for the REV in the dynamic curving regime traveling in the CCW direction. The model predicts a lower maximum carbody roll angle, much lower maximum wheel and truck-side L/V ratios, a higher minimum wheel load, and a slightly lower maximum carbody vertical acceleration with AAR-2A wheel profiles. However, the model also predicts that the AAR-1B profile will produce a slightly lower peak-to-peak carbody lateral acceleration.

Figure 26 plots the maximum wheel L/V ratio against speed for simulations of the REV in the CCW direction. At speeds below 12 mph, the model predicts slightly better performance with the AAR-1B profiles, but for speeds above 18 mph, the AAR-2A wheels perform much better.

Table 21. REV dynamic curving CCW

Criterion	S-2043 Limiting Value	Model of Dynamic Curving AAR-2A	Model of Dynamic Curving AAR-1B
Maximum carbody roll angle (degree)	4.0	1.0	1.4
Maximum wheel L/V ratio	0.80	0.64	0.76
Maximum truck-side L/V ratio	0.50	0.19	0.35
Minimum vertical wheel load (%)	25%	62%	53%
Peak-to-peak carbody lateral acceleration (g)	0.6	0.35	0.31
Maximum carbody lateral acceleration (g)	0.35	0.20	0.21
Maximum carbody vertical acceleration (g)	0.60	0.08	0.10
Maximum vertical suspension deflection (%)	95%	25%	45%

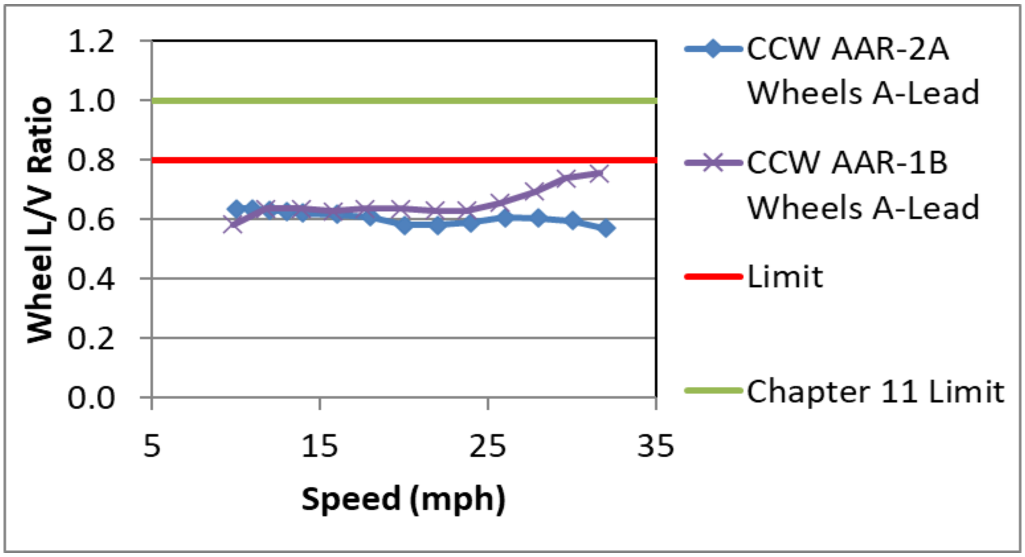

Figure 26. Predicted maximum wheel L/V ratios for the REV in dynamic curving in the CCW direction when equipped with AAR-2A and AAR-1B profile wheels

The model predicts the REV will meet all Standard S-2043 criteria in the dynamic curving regime in both the CW and CCW directions with both AAR-1B and AAR-2A wheel profiles. The overall performance of the AAR-2A is predicted to be better.

6.2 Hunting

Simulations of the REV in the hunting regime were conducted according to Standard S-2043, paragraph 4.3.11.3.1 to compare the performance of idealized KR profiles with idealized AAR-2A wheel profiles. The KR profile wheels were chosen for the hunting simulations instead of AAR-1B profile wheels due to the fact that the KR profile wheels represent a slightly worn profile, similar to the AAR-1B after 50,000–100,000 miles of wear, that is more likely to cause hunting in vehicles that have a tendency for lateral instability. Prior to the introduction of the AAR-2A wheel in 2020, Standard S-2043 required KR wheels for hunting tests and simulations. A substitute "worn profile" is not required by the current Standard S-2043 for the AAR-2A because the shape of the AAR-2A profile does not change much during initial wear. The simulations started at 30 mph and increased in 5 mph increments up to 75 mph for the model configured with KR wheel profiles and up to 80 mph for the model configured with AAR-2A profiles.

Table 22 presents the worst-case simulation predictions for the REV in the hunting regime. The model predicts lower maximum wheel and truck-side L/V ratios with AAR-2A wheel profiles. However, the model also predicts that the KR profiles will produce a slightly higher minimum vertical wheel load and a lower maximum carbody vertical acceleration. The model configured with either AAR-2A or the KR profile wheels meets the Standard S-2043 limit for the maximum standard deviation of the carbody lateral acceleration.

Figure 27 shows the maximum standard deviation of the carbody lateral acceleration calculated over a sliding 1,000-foot window plotted against speed for the REV. The plot compares the predicted performance of the REV when fitted with wheels having AAR-2A profiles with the predicted performance for the car when fitted with wheels having KR profiles. The predicted lateral stability of the car is better when fitted with KR profiles wheels until about 50 mph. Between 50 and 55 mph, the relative performances of the two profiles reverse, and the AAR-2A has better lateral stability.

Table 22. REV hunting

Criterion	S-2043 Limiting Value	Model of Hunting AAR-2A	Model of Hunting KR
Maximum carbody roll angle (degree)	4.0	0.4	0.4
Maximum wheel L/V ratio	0.80	0.17	0.22
Maximum truck-side L/V ratio	0.50	0.14	0.19
Minimum vertical wheel load (%)	25%	64%	66%
Peak-to-peak carbody lateral acceleration (g)	0.60	0.46	0.47
Maximum carbody lateral acceleration (g)	0.35	0.25	0.25
Std dev carbody lateral acceleration (g)	0.13	0.13	0.13
Maximum carbody vertical acceleration (g)	0.60	0.30	0.24
Maximum vertical suspension deflection (%)	95%	24%	40%

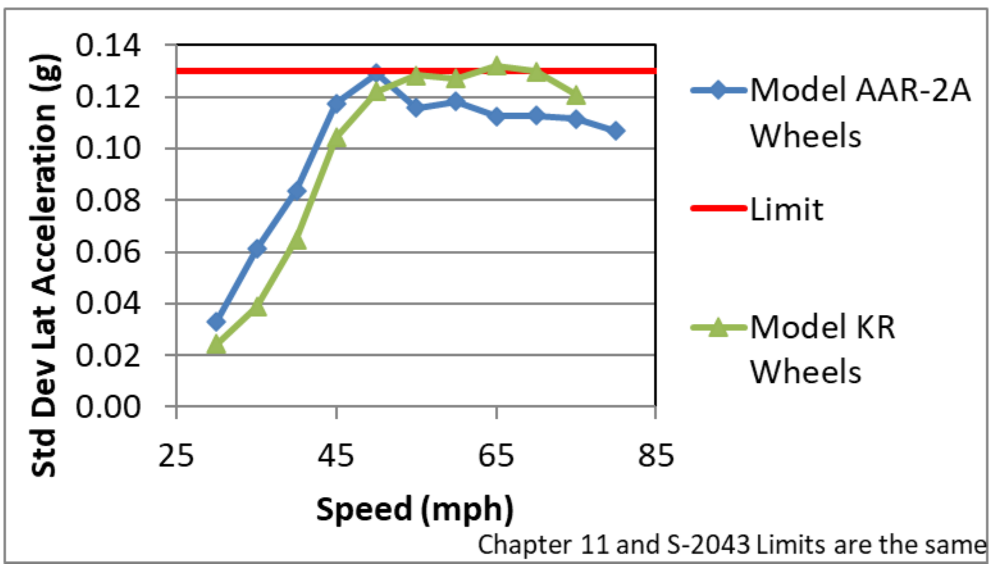

Figure 27. Predicted maximum standard deviation of the carbody lateral acceleration for the REV in hunting when equipped with AAR-2A and KR profile wheels

The model predicts that the REV will meet all Standard S-2043 criteria in the hunting regime with the AAR-2A and the KR wheel profiles. However, both wheel profiles produce standard deviations of the carbody lateral acceleration that are right at the limit. Results[8] of the test performed with the REV using KR wheel profiles did not met Standard S-2043 criterion for speeds above 65 mph. The EEC accepted the test results because the acceleration levels only moderately exceeded the limit and because the car will be limited to less than 50 mph by AAR Operating Transportation (OT) circular OT-55 when in HLRM service.

6.3 Yaw and Sway

Simulations of the yaw-and-sway regime were conducted according to Standard S-2043, paragraph 4.3.9.8 to compare the performance of idealized AAR-1B wheel profiles with idealized AAR-2A wheel profiles. The yaw-and-sway regime consists of a series of five consecutive 1.25-inch lateral deviations that input lateral and yaw motions on the car over a track section with a 1-inch-wide gage. The yaw-and-sway simulations were run at speeds from 30 to 75 mph in 5 mph increments.

Table 23 summarizes the worst-case simulation predictions for the REV in the yaw-and-sway regime. For the most part, there is not much difference in the predicted performance of the two wheel profiles. The largest differences in the predicted performance are the maximum carbody lateral acceleration and the maximum peak-to-peak carbody lateral acceleration, both of which are predicted to be much lower with AAR-2A profiles. Despite the improved performance, the maximum lateral and maximum peak-to-peak lateral accelerations do not meet the Standard S-2043 criteria for occupant carrying railcars with either the AAR-2A or AAR-1B wheel profiles, although they do meet the Standard S-2043 criteria for non-occupant carrying railcars (1.3 g for peak to peak and 0.75 g for maximum lateral acceleration).

Figure 28 plots the maximum peak-to-peak carbody lateral acceleration against the speed for the REV in the yaw-and-sway regime. The plot compares the predicted performance of the REV when fitted with wheels having AAR-2A profiles with the predicted performance for the car when fitted with wheels having AAR-1B profiles. The model configured with AAR-2A profiles produces peak-to-peak carbody lateral acceleration very similar to the model configured with AAR 1B profiles for speeds up to 65 mph, beyond which the AAR-1B has higher acceleration. The simulation predictions for both profiles do not meet the Standard S-2043 criterion for occupant-carrying cars (0.60 g), but they do meet the criterion for non-occupant carrying cars (1.3 g).

Figure 29 plots the maximum carbody lateral acceleration against the speed for the REV in the yaw-and-sway regime. The plot compares the predicted performance of the REV when fitted with wheels having AAR-2A profiles with the predicted performance for the car when fitted with wheels having AAR-1B profiles. The maximum accelerations produced by the AAR-2A profiles do not become as large as those produced by the AAR-1B profiles, but the accelerations still exceed the Standard S-2043 maximum limit for cars carrying occupants (0.35 g). The results for both profiles meet the Standard S-2043 criterion for non-occupant carrying railcars (1.3 g).

Table 23. REV yaw and sway

Criterion	S-2043 Limiting Value	Model of Yaw and Sway AAR-2A	Model of Yaw and Sway AAR-1B
Maximum carbody roll angle (degree)	4.0	1.1	1.1
Maximum wheel L/V ratio	0.80	0.71	0.71
Maximum truck-side L/V ratio	0.50	0.37	0.38
Minimum vertical wheel load (%)	25%	64%	65%
Peak-to-peak carbody lateral acceleration (g)	0.60	0.71	0.83
Maximum carbody lateral acceleration (g)	0.35	0.38	0.53
Maximum carbody vertical acceleration (g)	0.60	0.27	0.28
Maximum vertical suspension deflection (%)	95%	23%	19%

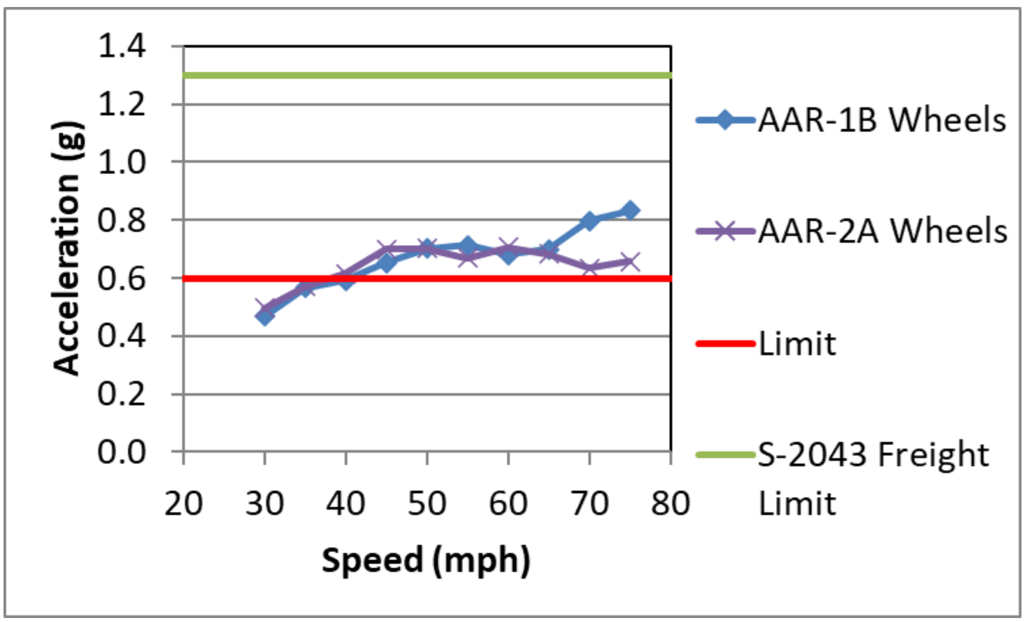

Figure 28. Predicted maximum peak-to-peak carbody lateral acceleration for the REV in yaw-and-sway when equipped with AAR-2A and AAR-1B profile wheels

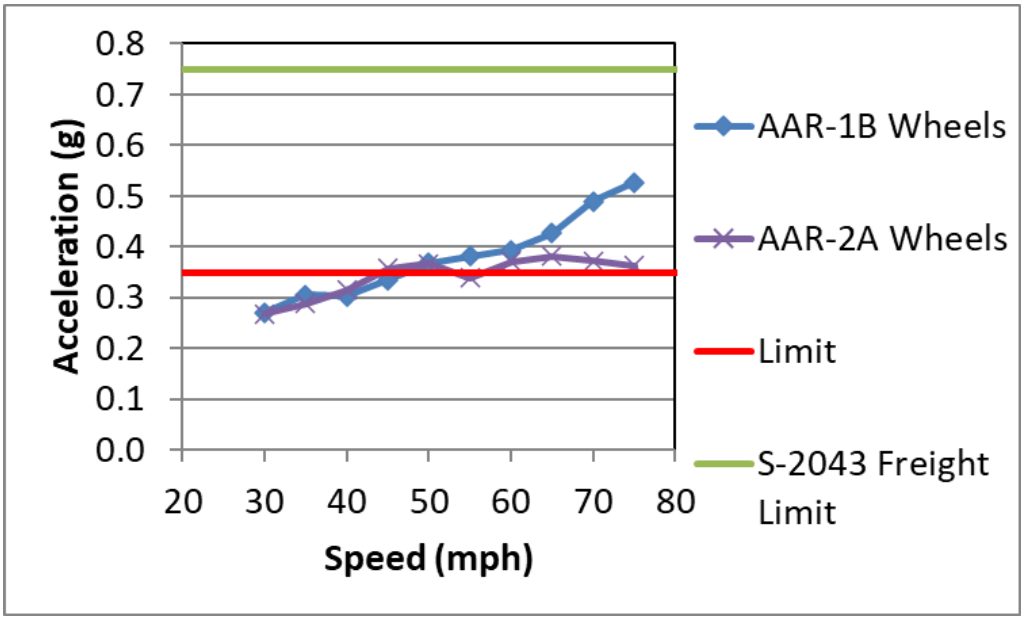

Figure 29. Predicted maximum carbody lateral acceleration for the REV in yaw-and-sway when equipped with AAR-2A and AAR-1B profile wheels

The model predicts that the REV exceeds the Standard S-2043 occupant limit for both the maximum carbody lateral acceleration and the maximum peak-to-peak carbody lateral acceleration in yaw-and-sway with either AAR-1B or AAR-2A wheel profiles. The simulation predictions for lateral carbody acceleration meet the Standard S-2043 criteria for non-occupant-carrying railcars. Results[8] from tests with the REV using the AAR-1B wheel profile did not met Standard S-2043 criterion for peak-to-peak lateral carbody acceleration or maximum lateral carbody acceleration. The EEC accepted the test results because the acceleration levels only moderately exceeded the limit and remained well below the S-2043 freight limit for these metrics.

6.4 Curving with Single Bump/Dip

Simulations of curving with a single-rail perturbation were conducted using a measured track input file to simulate the on-track test of the REV done during single car testing. The tests are performed with a two-inch amplitude bump and a two-inch amplitude dip separated by about 250-feet so that the car has time to return to nominal curving behavior between the perturbations. The inside rail bump was a flat-topped ramp with an elevation change over 6 track feet, a steady elevation over 12 track feet, and then a ramp back down over 6 track feet. The outside rail dip was the reverse. The simulations were performed at speeds from 4 to 15 mph in 2 mph increments.

Table 24 shows the worst-case simulation predictions for the REV in the curving-with-a-single-bump regime. The AAR-2A profile produces both a slightly higher maximum single wheel and truck-side L/V ratio than simulations with the AAR-1B profile. Otherwise, the predicted performance of the two wheel profiles is the same or nearly the same.

Figure 30 plots the maximum wheel L/V ratio against the speed for the REV in a curve with a single bump. The plot compares the predicted performance of the REV when fitted with wheels having AAR-2A and AAR-1B profiles together with test data from the single car test with AAR-1B profiles. The predicted performance with the AAR-2A profile shows slightly higher wheel L/V ratios across the speed range, especially in the CCW direction.

Table 24. REV curving with single bump

Criterion	S-2043 Limiting Value	Simulation Predictions Curving with Single Bump, 2-inch measured track input file			
		CW		CCW	
		AAR-2A	AAR-1B	AAR-2A	AAR-1B
Maximum carbody roll angle (degree)	4.0	3.3	3.3	1.9	1.9
Maximum wheel L/V ratio	0.80	0.56	0.54	0.79	0.73
Maximum truck-side L/V ratio	0.50	0.23	0.21	0.26	0.21
Minimum vertical wheel load (%)	25%	59%	59%	65%	66%
Peak-to-peak carbody lateral acceleration (g)	0.60	0.15	0.14	0.13	0.13
Maximum carbody lateral acceleration (g)	0.35	0.12	0.11	0.10	0.10
Maximum carbody vertical acceleration (g)	0.60	0.00	0.07	0.00	0.09
Maximum vertical suspension deflection (%)	95%	0.07	49%	0.09	47%

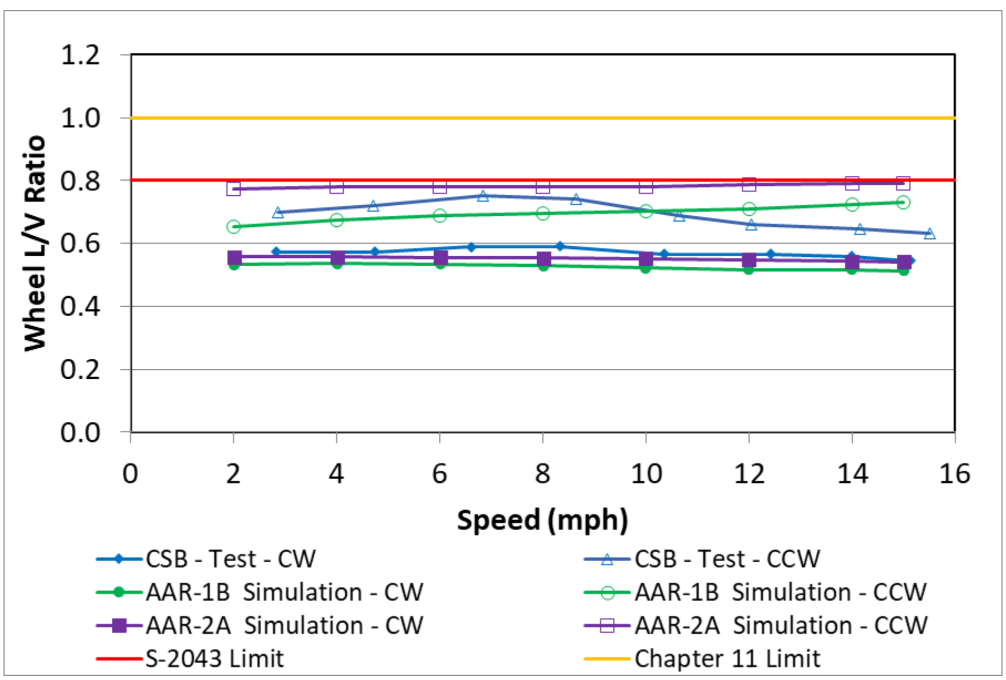

Figure 30. Predicted maximum wheel L/V ratios for the REV in curving with a single 2-inch bump when equipped with AAR-2A and AAR-1B profile wheels

Table 25 shows the worst-case simulation predictions for the REV in the curving with the curve with single dip regime. Simulation predictions are very similar for the AAR-1B and AAR-2A wheel profiles.

Figure 31 shows the maximum wheel L/V ratio plotted against speed for the REV in the curve with single dip. The plot compares the predicted performance of the REV equipped with AAR-2A and AAR-1B wheel profiles as well as single car test results with AAR-1B wheel profiles. The predicted performance of the two profiles is very similar.

Table 25. REV curving with single dip

Criterion	S-2043 Limiting Value	Simulation Predictions Curving with Single Dip, 2-inch measured track input file			
		CW		CCW	
		AAR-2A	AAR-1B	AAR-2A	AAR-1B
Maximum carbody roll angle (degree)	4.0	2.9	2.9	1.8	1.7
Maximum wheel L/V ratio	0.80	0.54	0.48	0.66	0.67
Maximum truck-side L/V ratio	0.50	0.21	0.21	0.21	0.29
Minimum vertical wheel load (%)	25%	57%	56%	66%	66%
Peak-to-peak carbody lateral acceleration (g)	0.60	0.12	0.12	0.12	0.12
Maximum carbody lateral acceleration (g)	0.35	0.10	0.10	0.08	0.11
Maximum carbody vertical acceleration (g)	0.60	0.09	0.09	0.08	0.08
Maximum vertical suspension deflection (%)	95%	48%	48%	39%	38%

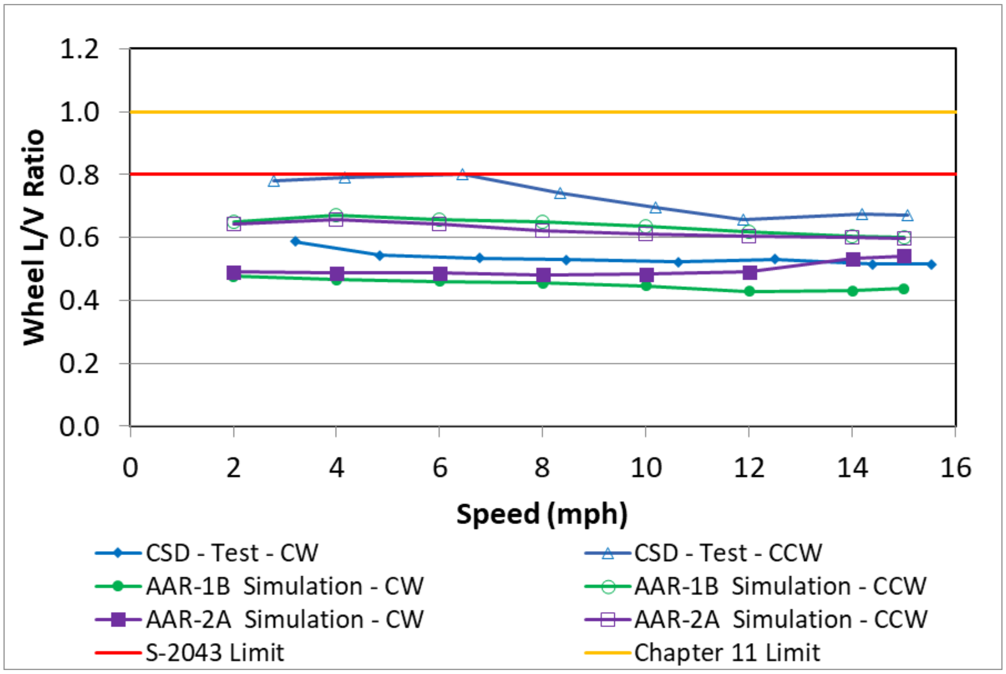

Figure 31. Predicted maximum wheel L/V ratios for the REV in curving with a single 2-inch dip when equipped with AAR-2A and AAR-1B profile wheels

The model predicts that the REV meets all Standard S-2043 criteria in the curving-with-a-single-bump and the curving-with-a-single-dip regime with both the AAR-2A and the AAR-1B wheel profiles.

6.5 No. 7 Crossover

The simulations for the No. 7 crossover were conducted according to Standard S-2043, paragraph 4.3.11.7 to compare the performance of AAR-1B with AAR-2A wheel profiles. The simulations were run at speeds from 3 to 15 mph in 2 mph increments.

Table 26 shows the worst-case simulation predictions for the REV in a No. 7 crossover. The predicted performance of the AAR-2A and AAR-1B profiles is similar. The model configured with AAR-2A profiles does produce a somewhat lower maximum carbody vertical acceleration. The model configured with AAR-1B profiles produces a slightly lower maximum peak-to-peak carbody lateral acceleration. The maximum truck-side L/V ratio exceeds the Standard S-2043 limit for both the model configured with the AAR-2A profiles and the model configured with the AAR-1B profiles but meets the Chapter 11 limit for both cases.

Figure 32 plots the maximum wheel L/V ratio against speed for the REV in a No. 7 crossover. The plot compares the predicted performance of the REV when fitted with AAR-2A profile wheels with the predicted performance for the REV when fitted with AAR-1B profile wheels. The predicted performance of the two profiles is nearly identical with their time-history plots falling basically on top of each other.

Table 26. REV No. 7 crossover

Criterion	S-2043 Limiting Value	Model AAR-2A	Model AAR-1B
Maximum carbody roll angle (degree)	4.0	0.3	0.3
Maximum wheel L/V ratio	0.80	0.76	0.75
Maximum truck-side L/V ratio	0.50	0.54	0.54
Minimum vertical wheel load (%)	25%	68%	68%
Peak-to-peak carbody lateral acceleration (g)	0.60	0.27	0.25
Maximum carbody lateral acceleration (g)	0.35	0.16	0.15
Maximum carbody vertical acceleration (g)	0.60	0.19	0.21
Maximum vertical suspension deflection (%)	95%	19%	22%

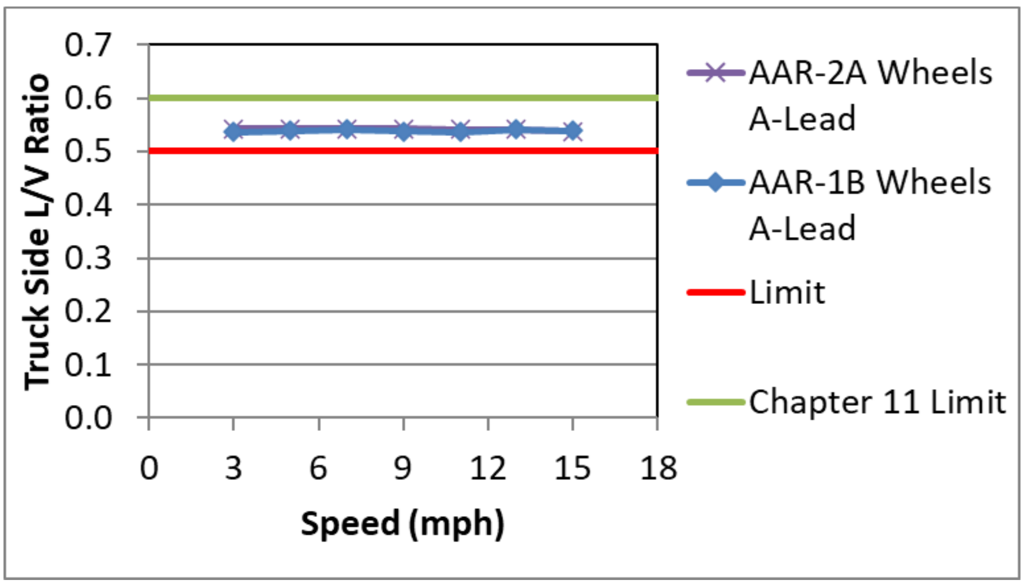

Figure 32. Predicted maximum truck-side L/V ratios for the REV with the A-End leading in a No. 7 crossover when equipped with AAR-2A and AAR-1B profile wheels

The model predicts that the REV exceeds the Standard S-2043 limit for the maximum truck-side L/V ratio in a No. 7 crossover when equipped with either AAR-2A or AAR-1B profiles, but both are less than the Chapter 11 limit.

6.6 Ride Quality

The ride quality simulations were conducted according to Standard S-2043, Section 4.3.12 to compare the performance of idealized AAR-1B with idealized AAR-2A wheel profiles. The simulations were run at the following speeds:

- Class 2 track: 10 to 25 mph in 5 mph increments
- Class 3 track: 10 to 40 mph in 5 mph increments

- Class 4 track: 10 to 60 mph in 5 mph increments
- Class 5 and 6 track: 10 to 75 mph in 5 mph increments

Table 27 presents the worst-case simulation predictions for the REV on Class 2 track. The predicted performance of the AAR-2A and AAR-1B profiles is mixed. The model configured with AAR-2A profiles does produce a lower maximum truck-side L/V ratio and a lower peak-to-peak carbody lateral acceleration. However, the model configured with AAR-1B profiles produces a slightly higher minimum vertical wheel load and a slightly lower maximum carbody vertical acceleration.

Figure 33 shows the maximum vertical acceleration plotted against speed for the REV on Class 2 track. The plot compares the predicted performance of the REV when fitted with AAR-2A profile wheels with the predicted performance for the REV fitted with AAR-1B profile wheels. The predicted performance of the two profiles is nearly the same. The time-history plots overlay each other for most of the range of speeds and only begin to diverge at the maximum simulated speed.

Figure 34 shows the predicted maximum RMS lateral acceleration plotted against speed for an accelerometer located at floor level toward the leading end of the REV. The plot compares the perceived ride quality as defined by the ISO 2631[9] standard for the REV on Class 2 track when equipped with AAR-2A profile wheels with the ride quality of the REV equipped with AAR-1B profile wheels. The two profiles start out at the same level but begin to diverge immediately. By 25 mph, the lateral acceleration predicted for the AAR-2A profile is noticeably higher than the lateral acceleration predicted for the AAR-1B profile.

Table 27. REV ride quality Class 2 track

Criterion	S-2043 Limiting Value	Model of AAR-2A on Class 2 Track	Model of AAR-1B on Class 2 Track
Maximum carbody roll angle (degree)	4.0	1.9	1.9
Maximum wheel L/V ratio	0.80	0.66	0.67
Maximum truck-side L/V ratio	0.50	0.28	0.32
Minimum vertical wheel load (%)	25%	64%	66%
Peak-to-peak carbody lateral acceleration (g)	0.60	0.24	0.29
Maximum carbody lateral acceleration (g)	0.35	0.18	0.17
Std dev carbody lateral acceleration (g)	0.13	0.04	0.04
Maximum carbody vertical acceleration (g)	0.60	0.27	0.25
Maximum vertical suspension deflection (%)	95%	38%	40%

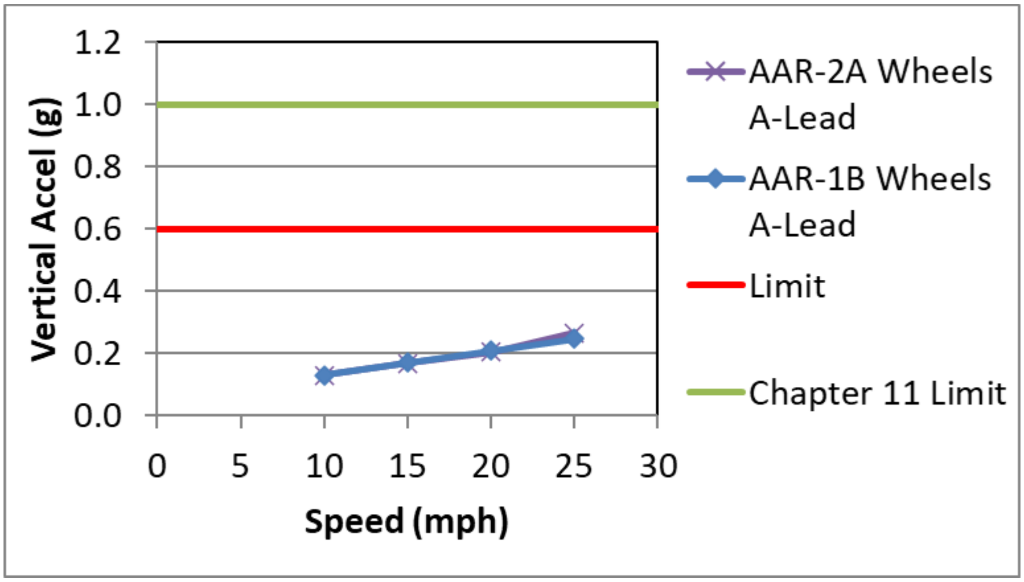

Figure 33. Predicted maximum vertical acceleration for the REV on Class 2 track when equipped with AAR-2A and AAR-1B profile wheels

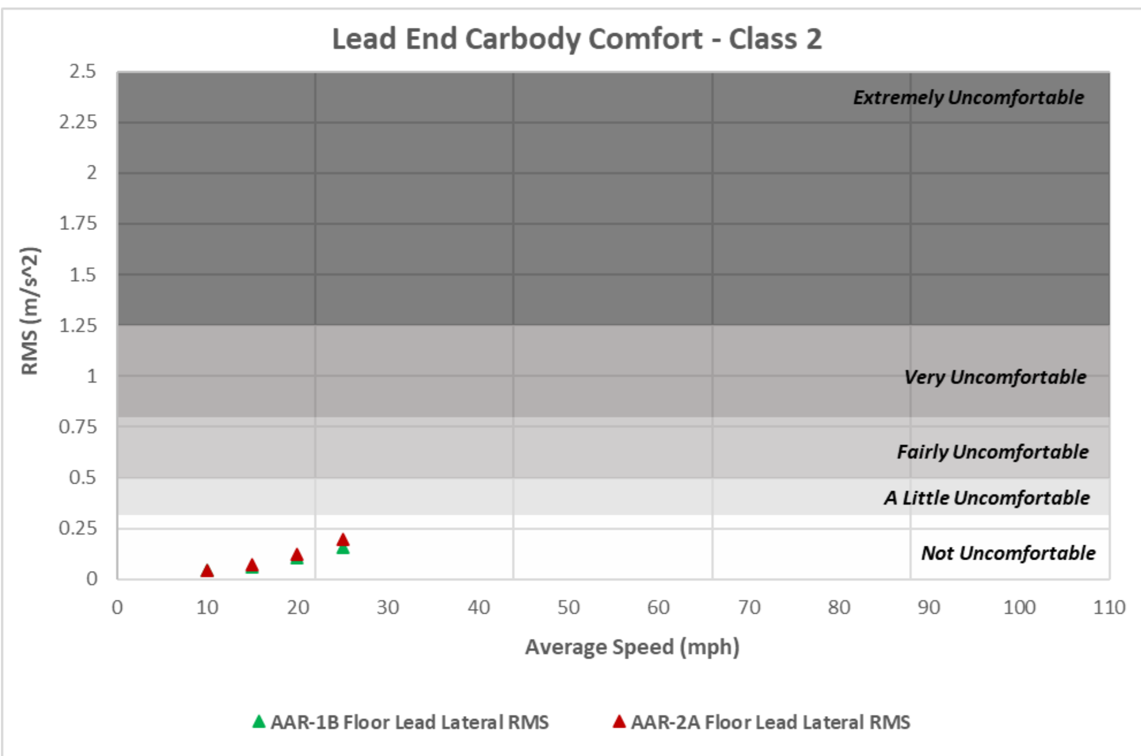

Figure 34. Comparison of predicted RMS lateral accelerations for the REV equipped with AAR-2A and AAR-1B profile wheels on Class 2 track for ISO 2631 ride quality analysis

Table 28 shows the worst-case simulation predictions for the REV on Class 3 track. The predicted performance of AAR-1B wheel profiles is a little better than the AAR-2A wheel profiles. The model configured with AAR-2A profiles does produce a lower maximum wheel

L/V ratio. However, the model configured with AAR-1B profiles produces a lower maximum truck-side L/V ratio as well as a lower maximum carbody lateral acceleration, a lower maximum peak-to-peak carbody lateral acceleration, and a lower standard deviation of the carbody lateral acceleration.

Figure 35 plots the maximum vertical acceleration against speed for the REV on Class 3 track. The plot compares the predicted performance of the REV when fitted with AAR-2A profile wheels with the predicted performance for the REV when fitted with AAR-1B profile wheels. The predicted performance of the two profiles is basically identical. The time-history plots overlay each other for the entire range of speeds simulated.

Figure 36 shows the predicted maximum RMS lateral acceleration plotted against the speed for an accelerometer located at floor level toward the leading end of the REV. The plot compares the perceived ride quality as defined by the ISO 2631 standard for the REV on Class 3 track when equipped with AAR-2A profile wheels with the perceived ride quality of the REV equipped with AAR-1B profile wheels. Similar to the results for Class 2 track, the predicted accelerations of the two wheel profiles on Class 3 track start out at the same level but diverge even more quickly than they do for Class 2 track. By 40 mph, the acceleration predicted for the AAR-2A profile wheels is almost double the acceleration predicted for the AAR-1B profile wheels. This result is not entirely unexpected because the AAR-2A profile is similar to a worn AAR-1B profiles.

Table 28. REV ride quality Class 3 track

Criterion	S-2043 Limiting Value	Model of AAR-2A on Class 3 Track	Model of AAR-1B on Class 3 Track
Maximum carbody roll angle (degree)	4.0	1.2	1.2
Maximum wheel L/V ratio	0.80	0.53	0.60
Maximum truck-side L/V ratio	0.50	0.23	0.20
Minimum vertical wheel load (%)	25%	62%	61%
Peak-to-peak carbody lateral acceleration (g)	0.60	0.51	0.47
Maximum carbody lateral acceleration (g)	0.35	0.30	0.25
Std dev carbody lateral acceleration (g)	0.13	0.12	0.08
Maximum carbody vertical acceleration (g)	0.60	0.47	0.47
Maximum vertical suspension deflection (%)	95%	66%	66%

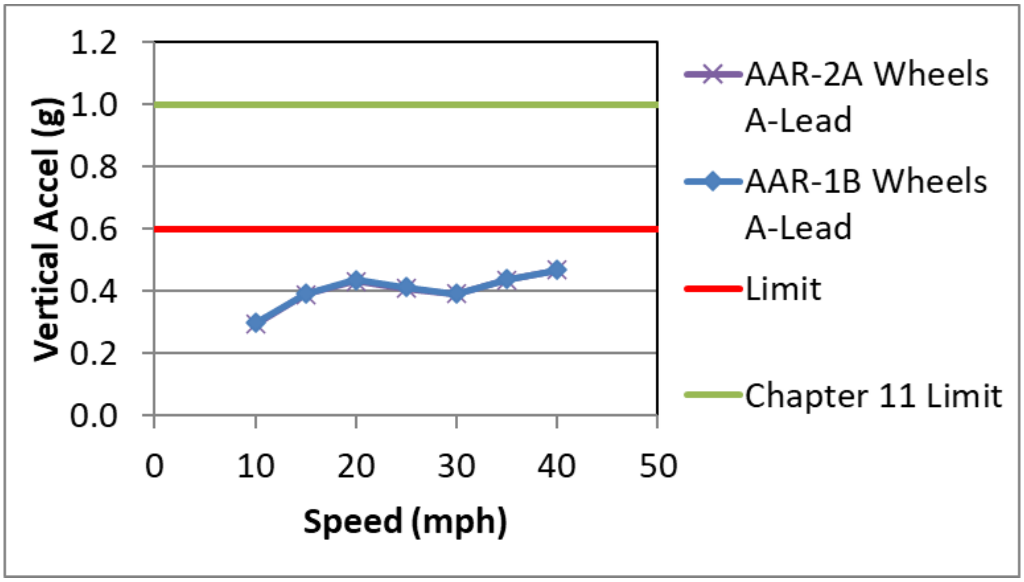

Figure 35. Predicted maximum vertical acceleration for the REV on Class 3 track when equipped with AAR-2A and AAR-1B profile wheels

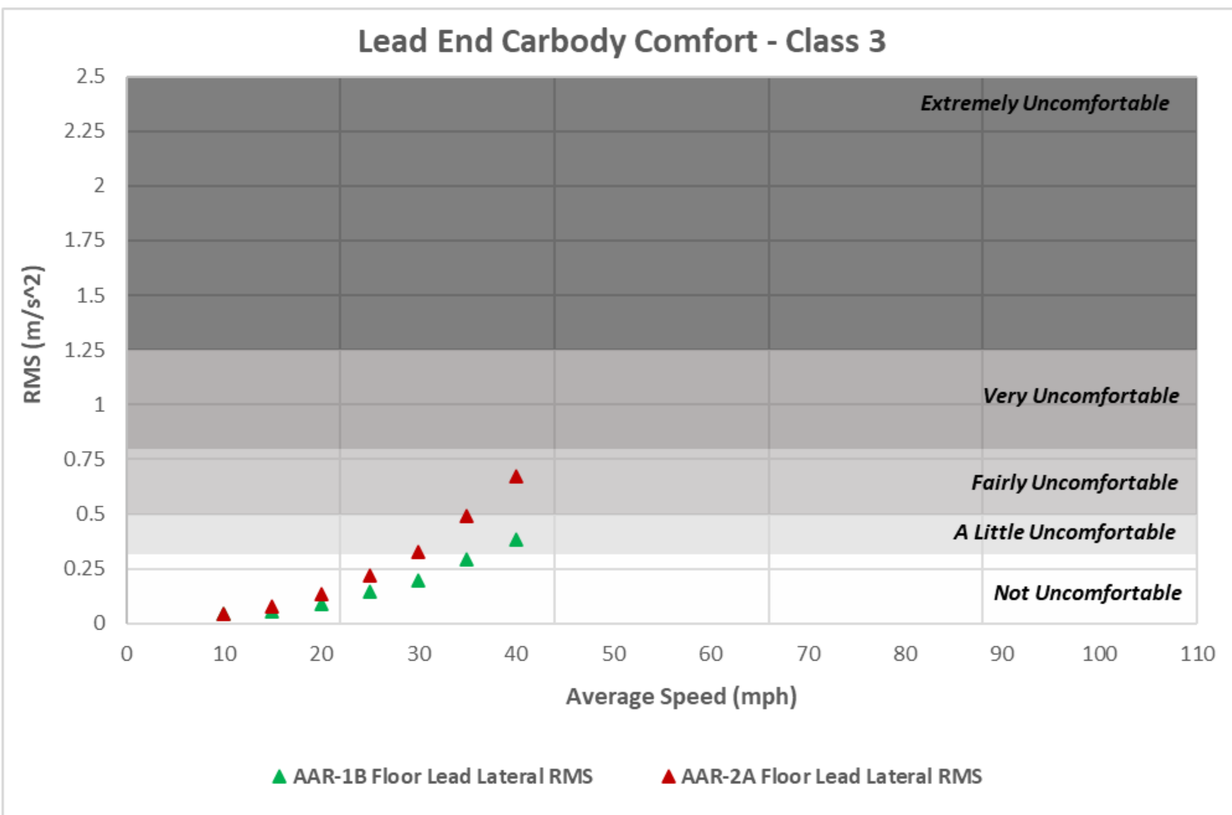

Figure 36. Comparison of predicted RMS lateral accelerations for the REV equipped with AAR-2A and AAR-1B profile wheels on Class 3 track for ISO 2631 ride quality analysis

Table 29 shows the worst-case simulation predictions for the REV on Class 4 track. The predicted performance of the AAR-1B and AAR-2A wheel profiles is not very good for this regime. The model configured with AAR-2A profiles produces somewhat lower maximum wheel and truck-side L/V ratios and a higher minimum vertical load, but this model also exceeds the Standard S-2043 limit for the standard deviation of the carbody lateral acceleration. The model configured with AAR-1B profiles produces a somewhat lower maximum carbody lateral acceleration, and the maximum standard deviation of the carbody lateral acceleration does not exceed the Standard S-2043 limit. However, the model predicts the REV will exceed the Standard S-2043 limit for the maximum carbody vertical acceleration at 55 and 60 mph with both the AAR-1B and the AAR-2A profile wheels.

Figure 37 plots the maximum standard deviation of the carbody lateral acceleration against speed for the REV on Class 4 track. The plot compares the predicted and test performance of the REV when fitted with AAR-2A profile wheels with the predicted and test performance for the REV fitted with AAR-1B profile wheels. The predicted performance of the two wheel profiles is very similar from 10 to 25 mph, but after that, the performance of the AAR-1B profiles is much better. Except for one data point with the AAR-2A profile at 37 mph, the test performance for the two profiles shows less increase in acceleration with speed than the simulation predictions.

Figure 38 shows the maximum vertical acceleration plotted against speed for the REV on Class 4 track. The plot compares the predicted and test performance of the REV when fitted with AAR-2A profile wheels with the predicted and test performance for the REV fitted with AAR-1B profile wheels. The predicted performance of the two profiles is very similar. The time-history plots overlay each other for most of the speeds simulated, and 55 mph is the only speed where the two plots clearly diverge. The test performance for the two profiles is also similar, following a trend similar to the model performance,

Figure 39 shows the predicted maximum RMS lateral acceleration plotted against speed for an accelerometer located at floor level toward the leading end of the REV. The plot compares the perceived ride quality as defined by the ISO 2631 standard for the REV on Class 4 track when equipped with AAR-2A profile wheels with the perceived ride quality of the REV equipped with AAR-1B profile wheels. The predicted accelerations of the two wheel profiles on Class 4 track start out at the same level and immediately start diverging. At 45 mph, the difference between the AAR-2A profile wheels and the AAR-1B profile wheels is at its' maximum, and after this speed the performance gap reduces significantly. Again, the relatively poor performance of the AAR-2A profiles is not unexpected due to their similarity to a worn AAR-1B profile.

Figure 40 overlays the test results on the modeling predictions from Figure 39. While the modeling predictions clearly diverge by 35 mph, the test data remains tightly grouped up to the maximum speed of just over 40 mph. The model data was generated using the S-2043 Class 4 input file provided by the AAR, representing about 4.3 miles of tangent track. The test data was recorded during the revenue service test runs between Avondale and Trinidad, representing about 110 miles of tangent and gently curved track. The Class 4 track case was one of the few cases where ride quality data were measured for both AAR-1B and AAR-2A profiles.

Table 29. REV ride quality Class 4 track

Criterion	S-2043 Limiting Value	Model of AAR-2A on Class 4 Track	Model of AAR-1B on Class 4 Track
Maximum carbody roll angle (degree)	4.0	1.1	1.0
Maximum wheel L/V ratio	0.80	0.53	0.55
Maximum truck-side L/V ratio	0.50	0.17	0.20
Minimum vertical wheel load (%)	25%	60%	56%
Peak-to-peak carbody lateral acceleration (g)	0.60	0.50	0.49
Maximum carbody lateral acceleration (g)	0.35	0.28	0.26
Std dev carbody lateral acceleration (g)	0.13	0.14	0.11
Maximum carbody vertical acceleration (g)	0.60	0.70	0.70
Maximum vertical suspension deflection (%)	95%	79%	84%

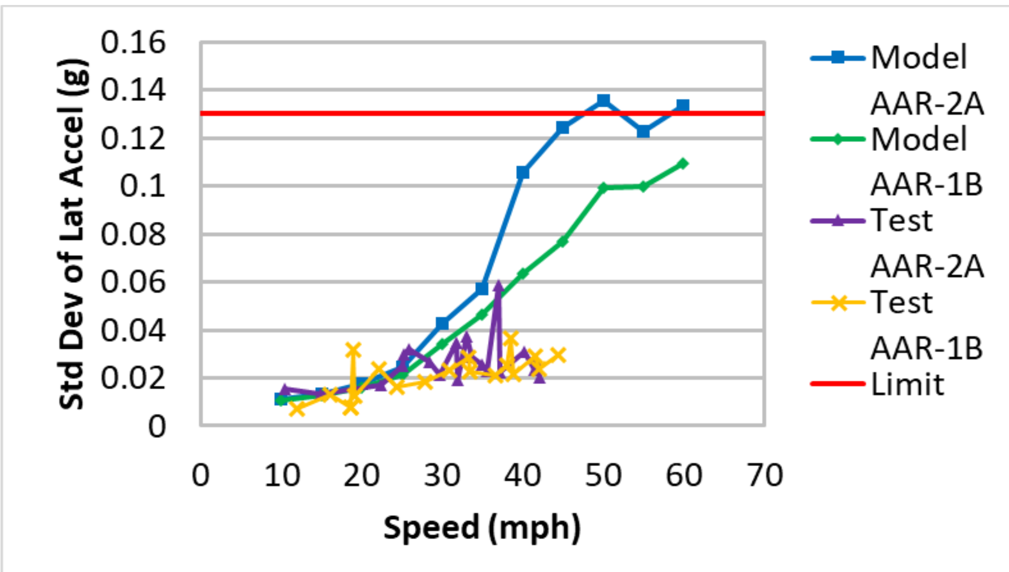

Figure 37. Maximum standard deviation of the carbody lateral acceleration for the REV on Class 4 track when equipped with AAR-2A and AAR-1B profile wheels

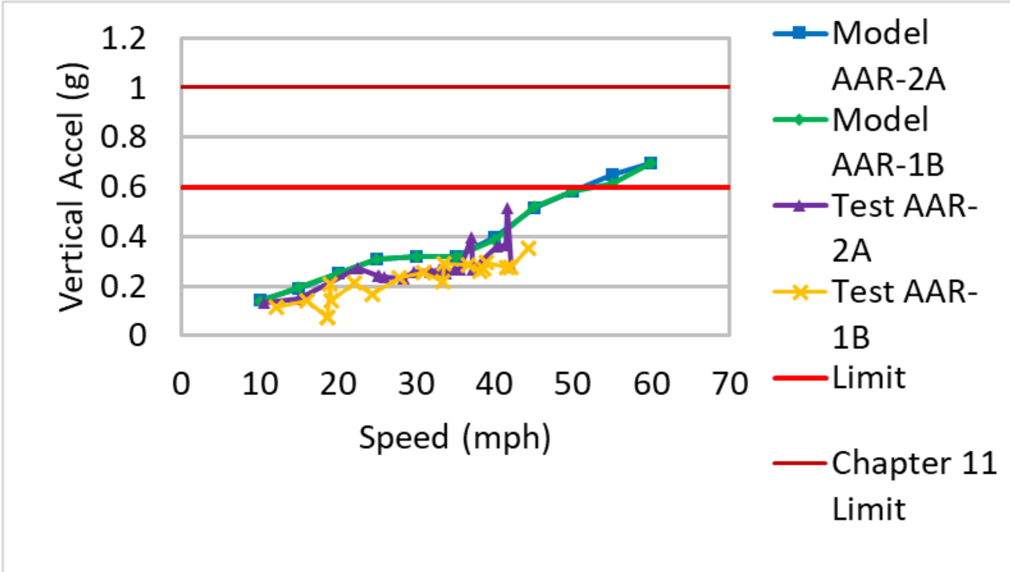

Figure 38. Maximum vertical acceleration for the REV on Class 4 track when equipped with AAR-2A and AAR-1B profile wheels

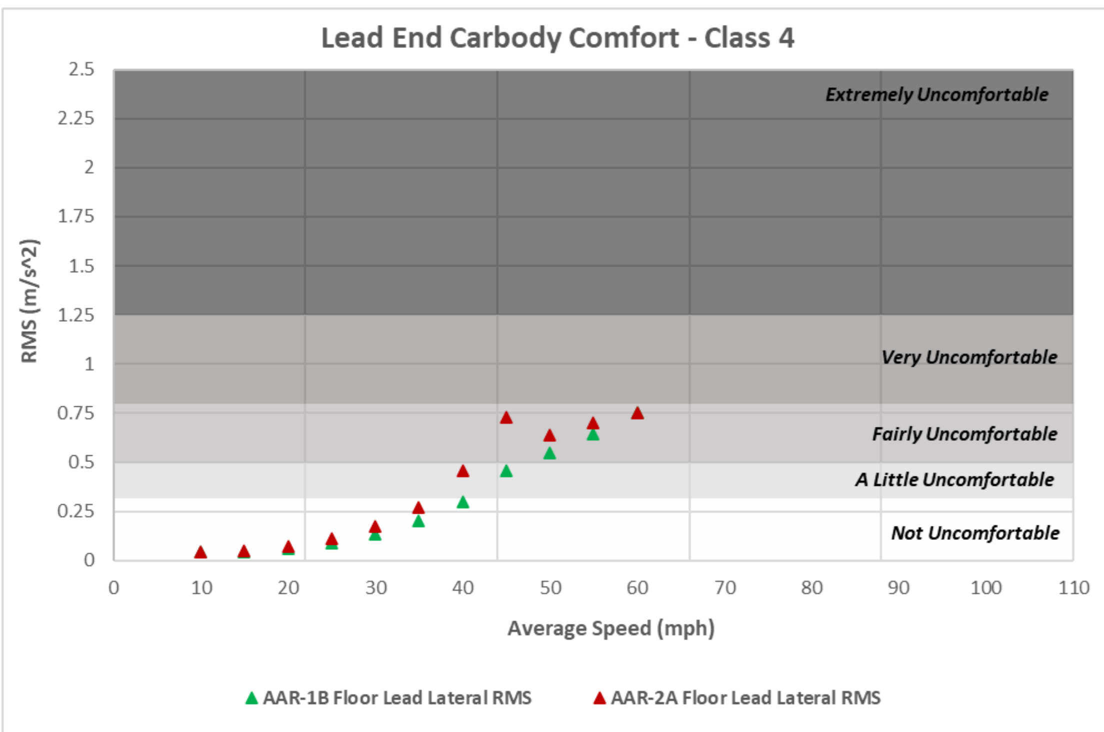

Figure 39. Comparison of predicted RMS lateral accelerations for the REV equipped with AAR-2A and AAR-1B profile wheels on Class 4 track for ISO 2631 ride quality analysis

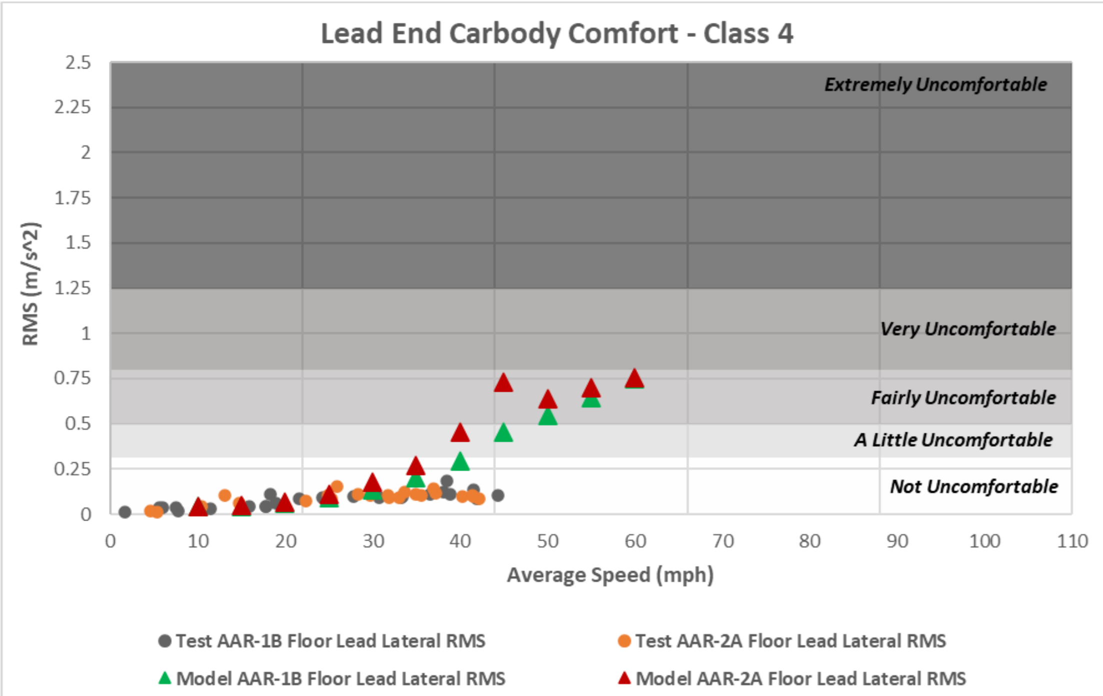

Figure 40. Comparison of predicted and actual RMS lateral accelerations for the REV on Class 4 track for ISO 2631 ride quality analysis

Table 30 shows the worst-case simulation predictions for the REV on Class 5 track. The model configured with AAR-2A profiles produces a somewhat lower maximum carbody roll angle. However, the model configured with AAR-1B profiles produces a lower truck-side L/V ratio, a higher minimum wheel load, and a lower maximum peak-to-peak lateral carbody acceleration. The table shows that the model configured with AAR-1B profile wheels reaches the Standard S-2043 limit of 0.13 for the standard deviation of the lateral acceleration, which may be a little misleading due to rounding. The value to three significant figures is 0.126 (compared to 0.122 for the model with AAR-2A profile wheels). Overall, the performance of the AAR-1B profiles is slightly better than the AAR-2A profile wheels.

Figure 41 plots the maximum vertical acceleration against speed for the REV on Class 5 track. The plot compares the predicted performance of the REV when fitted with AAR-2A profile wheels with the predicted performance for the REV fitted with AAR-1B profile wheels. The predicted performance of the two profiles is very similar. The time-history plots overlay each other from 10 to 40 mph and only show a very small offset at 45 mph and from 55 to 70 mph.

Figure 42 shows the predicted maximum RMS lateral acceleration plotted against speed for an accelerometer located at floor level toward the leading end of the REV. The plot compares the perceived ride quality as defined by the ISO 2631 standard for the REV on Class 5 track when equipped with AAR-2A profile wheels with the perceived ride quality of the REV equipped with AAR-1B profile wheels. The predicted accelerations of the two wheel profiles begin at the same level and start diverging by 15 mph. At 50 mph, the difference between the performance of the AAR-2A profile wheels and the AAR-1B profile wheels reaches its maximum. Between 65 and

70 mph, the relative predicted performance of the two wheel profiles reverse with the AAR-1B profiles producing higher RMS lateral accelerations.

Table 30. REV ride quality Class 5 track

Criterion	S-2043 Limiting Value	Model of AAR-2A on Class 5 Track	Model of AAR-1B on Class 5 Track
Maximum carbody roll angle (degree)	4.0	1.0	1.3
Maximum wheel L/V ratio	0.80	0.32	0.31
Maximum truck-side L/V ratio	0.50	0.19	0.17
Minimum vertical wheel load (%)	25%	52%	56%
Peak-to-peak carbody lateral acceleration (g)	0.60	0.53	0.49
Maximum carbody lateral acceleration (g)	0.35	0.29	0.29
Std dev carbody lateral acceleration (g)	0.13	0.12	0.13
Maximum carbody vertical acceleration (g)	0.60	0.43	0.43
Maximum vertical suspension deflection (%)	95%	55%	56%

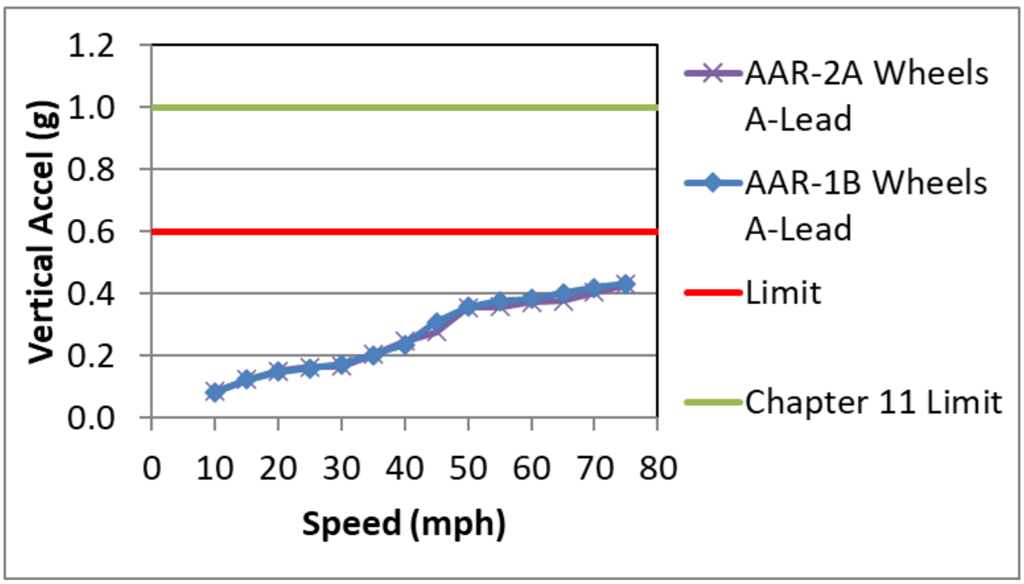

Figure 41. Predicted maximum vertical acceleration for the REV on Class 5 track when equipped with AAR-2A and AAR-1B profile wheels

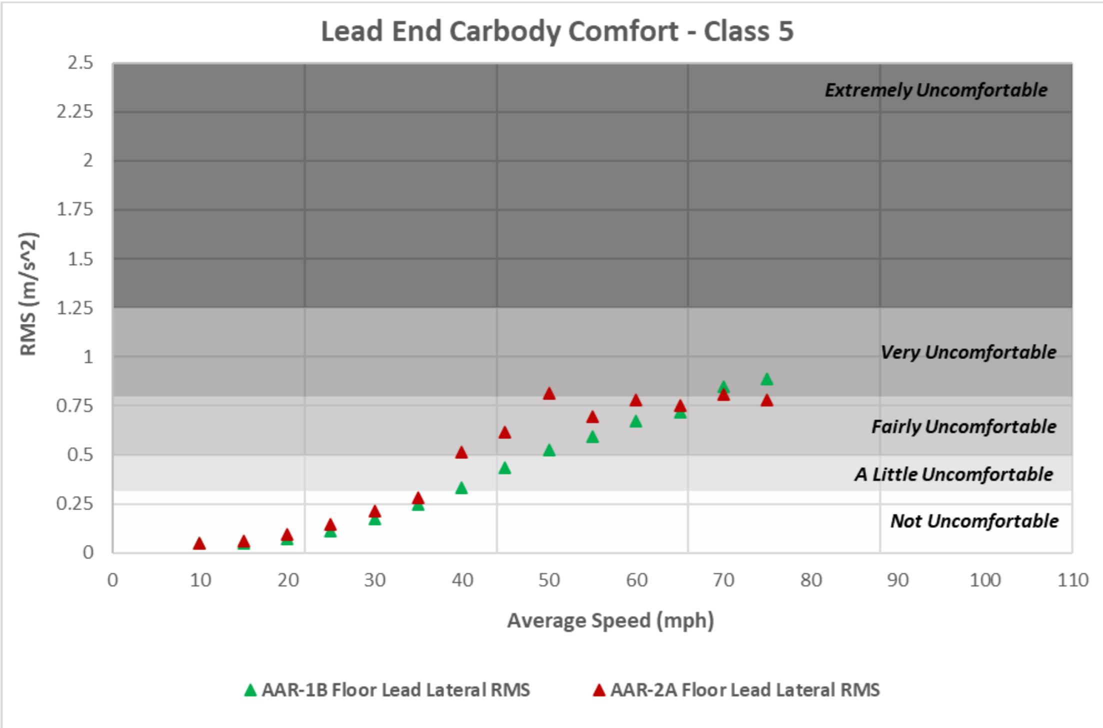

Figure 42. Comparison of predicted RMS lateral accelerations for the REV equipped with AAR-2A and AAR-1B profile wheels on Class 5 track for ISO 2631 ride quality analysis

Table 31 presents the worst-case simulation predictions for the REV on Class 6 track. The performance predicted for the REV configured with AAR-1B profile wheels compared to the performance predicted for the REV configured with AAR-2A profile wheels is somewhat mixed. The model configured with AAR-2A profiles produces somewhat lower maximum wheel and truck-side L/V ratios and a higher minimum vertical wheel load. The standard deviation of the carbody lateral acceleration meets the Standard S-2043 limit. The model configured with AAR-1B profiles produces a slightly lower maximum carbody roll angle. The maximum standard deviation of the carbody lateral acceleration meets the Standard S-2043 limit.

Figure 43 plots the maximum vertical acceleration against speed for the REV on Class 6 track. The plot compares the predicted performance of the REV when fitted with AAR-2A profile wheels with the predicted performance for the REV fitted with AAR-1B profile wheels. There is very little difference in the predicted performance of the two profiles. The time-history plots basically overlay each other over the full range of speeds simulated.

Figure 44 shows the predicted maximum RMS lateral acceleration plotted against speed for an accelerometer located at floor level toward the leading end of the REV. The plot compares the perceived ride quality as defined by the ISO 2631 standard for the REV on Class 6 track when equipped with AAR-2A profile wheels with the ride quality of the REV equipped with AAR-1B profile wheels. The predicted accelerations of the two wheel profiles begin at the same level, start diverging at 15 mph, and continue diverging until 50 mph. After 50 mph, the trend reverses, and by 60 mph, the two profiles again have approximately the same performance. After 60 mph, the relative performance of these two profiles reverses, with AAR-1B profiles producing higher maximum RMS lateral accelerations.

Table 31. REV ride quality Class 6 track

Criterion	S-2043 Limiting Value	Model of AAR-2A on Class 6 Track	Model of AAR-1B on Class 6 Track
Maximum carbody roll angle (degree)	4.0	1.9	1.6
Maximum wheel L/V ratio	0.80	0.28	0.31
Maximum truck-side L/V ratio	0.50	0.18	0.20
Minimum vertical wheel load (%)	25%	57%	52%
Peak-to-peak carbody lateral acceleration (g)	0.60	0.53	0.53
Maximum carbody lateral acceleration (g)	0.35	0.30	0.29
Std dev carbody lateral acceleration (g)	0.13	0.13	0.13
Maximum carbody vertical acceleration (g)	0.60	0.53	0.52
Maximum vertical suspension deflection (%)	95%	60%	57%

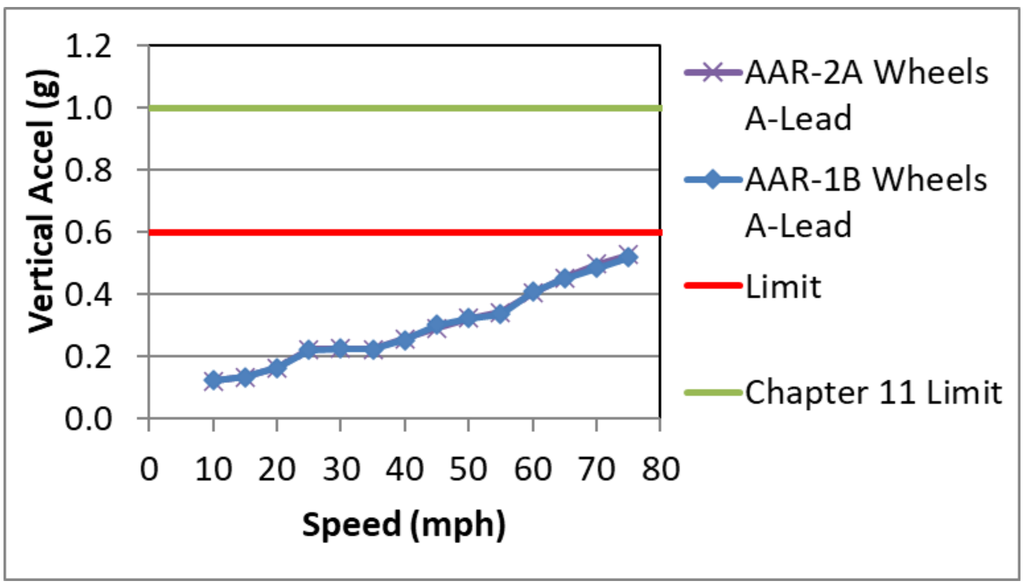

Figure 43. Predicted maximum vertical acceleration for the REV on Class 6 track when equipped with AAR-2A and AAR-1B profile wheels

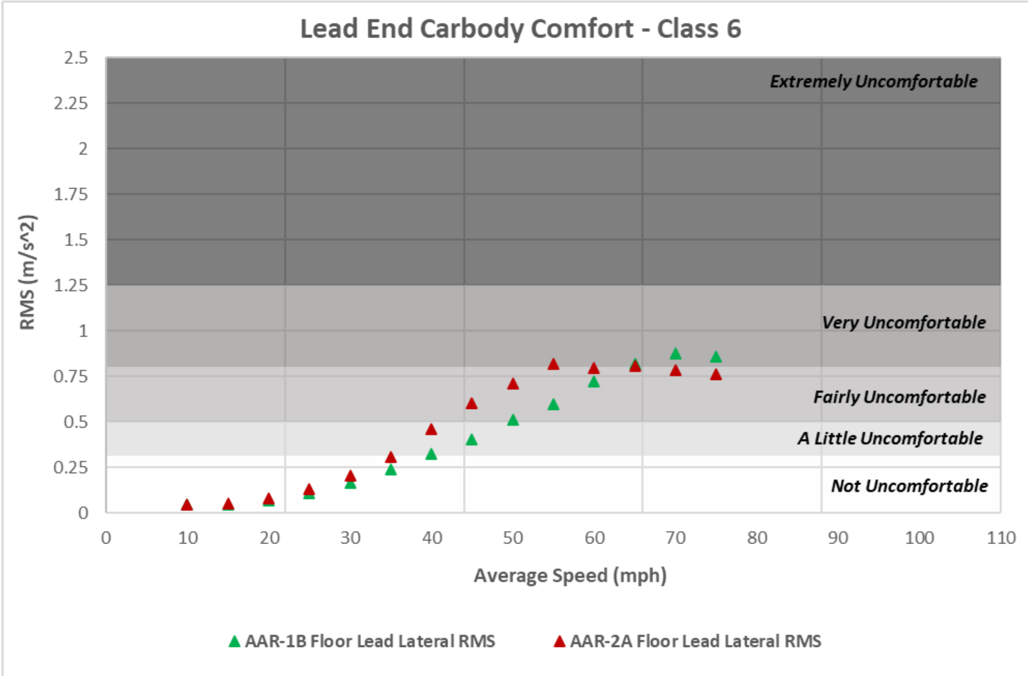

Figure 44. Comparison of predicted RMS lateral accelerations for the REV equipped with AAR-2A and AAR-1B profile wheels on Class 6 Track for ISO 2631 ride quality analysis

The model predicts that the REV meets all Standard S-2043 criteria on Class 2, Class 3, Class 5, and Class 6 track with either AAR-1B or AAR-2A profiles. However, the standard deviation of the carbody lateral acceleration is right at the limit with both the AAR-1B and the AAR-2A wheel profiles. The predicted perceived ride quality as defined by the ISO 2631 standard with the AAR-2A wheel is also somewhat worse than the ride quality with the AAR-1B wheel, although the limited test data on Class 4 track indicates very similar ride quality. On Class 4 track, the model also predicts that the REV does not meet the Standard S-2043 criteria for standard deviation of carbody lateral acceleration with the AAR-2A or the maximum carbody vertical acceleration with either AAR-1B or AAR-2A profiles. The model does not indicate a clearly superior wheel profile for the ride quality regime.

7.0 SELECT SINGLE CAR REGIMES -- BUFFER CAR

Two regimes, dynamic curving and hunting, were modeled for the Buffer car. These regimes were selected based on a request from the EEC (Appendix A) for follow-up modeling in areas where either the test or the modeling results of the car equipped with AAR-1B wheel profiles were borderline and could become problematic if switching over to AAR-2A profiles caused the performance to degrade significantly.

7.1 Dynamic Curving

Simulations of the dynamic curving regime were conducted according to Standard S-2043, paragraph 4.3.9.9 to compare the performance of idealized AAR-1B with idealized AAR-2A wheel profiles. The simulations were performed at speeds ranging from 10 mph to 32 mph in 1 mph increments from 10 to 14 mph and increments of 2 mph from 14 to 32 mph.

Table 32 shows the worst-case simulation predictions for the Buffer car in the dynamic curving regime traveling in the CW direction. The model predicts that the Buffer car equipped with AAR-1B wheel profiles will produce a lower maximum wheel L/V ratio, a higher minimum vertical wheel load, and significantly lower maximum carbody lateral and peak-to-peak carbody lateral accelerations. The model predicts that Buffer meets all Standard S-2043 criteria when configured with either AAR-1B or AAR-2A profile wheels.

Figure 45 plots the maximum wheel L/V ratio against the speed for simulations of the Buffer car on the dynamic curve in the CW direction. The plot compares the predicted performance of the Buffer car when fitted with wheels having AAR-2A profiles with the predicted performance for the car when fitted with wheels having AAR-1B profiles. The simulation predicts lower maximum wheel L/V ratios for the car when it is configured with AAR-1B wheel profiles for speeds between 10 and 18 mph and at 32 mph. The model predicts that the AAR-2A profiles produce lower maximum wheel L/V ratios at 24 to 26 mph.

Table 32. Buffer car dynamic curving CW

Criterion	S-2043 Limiting Value	Model of Dynamic Curving AAR-2A	Model of Dynamic Curving AAR-1B
Maximum carbody roll angle (degree)	4.0	1.0	1.0
Maximum wheel L/V ratio	0.80	0.57	0.51
Maximum truck-side L/V ratio	0.50	0.27	0.26
Minimum vertical wheel load (%)	25%	54%	58%
Peak-to-peak carbody lateral acceleration (g)	1.3	0.78	0.63
Maximum carbody lateral acceleration (g)	0.75	0.54	0.42
Maximum carbody vertical acceleration (g)	0.90	0.09	0.09
Maximum vertical suspension deflection (%)	95%	24%	34%

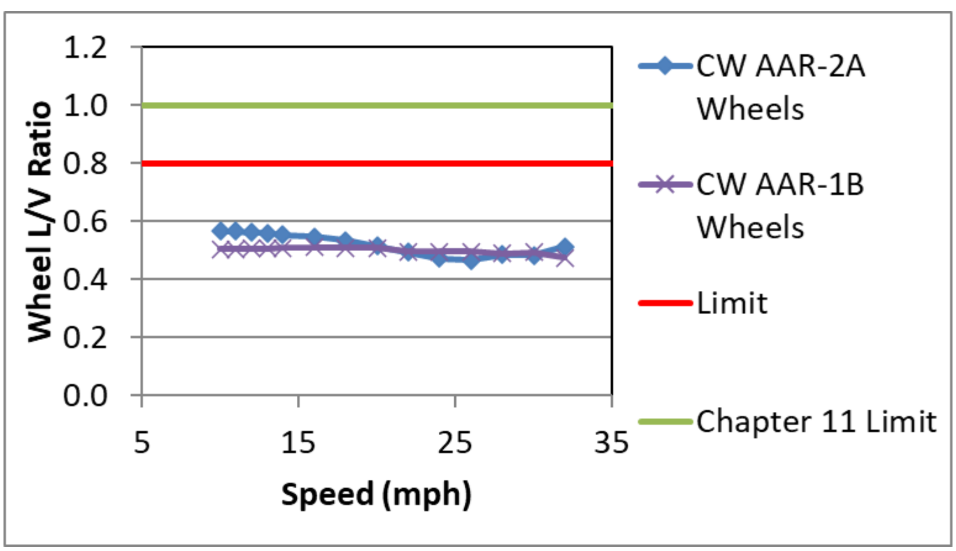

Figure 45. Predicted maximum wheel L/V ratios for the Buffer Car in dynamic curving in the CW direction when equipped with AAR-2A and AAR-1B profile wheels

Table 33 shows the worst-case simulation predictions for the Buffer car in the dynamic curving regime traveling in the CCW direction. The model predicts that the Buffer car equipped with AAR-2A wheel profiles will produce a slightly lower maximum wheel L/V ratio and maximum carbody vertical acceleration. The model also predicts that the Buffer car equipped with AAR-1B wheel profiles will produce a higher minimum vertical wheel load and significantly lower maximum carbody lateral and peak-to-peak lateral accelerations. The model predicts that the Buffer car meets all Standard S-2043 criteria when configured with either AAR-1B or AAR-2A profile wheels.

Figure 46 shows the maximum wheel L/V ratio plotted against the speed for simulations of the Buffer car on the dynamic curve in the CCW direction. The plot compares the predicted performance of the Buffer car when fitted with wheels having AAR-2A profiles with the predicted performance for the car when fitted with wheels having AAR-1B profiles. The simulation predicts lower maximum wheel L/V ratios for the car when it is configured with AAR-2A wheel profiles.

Table 33. Buffer car dynamic curving CCW

Criterion	S-2043 Limiting Value	Model of Dynamic Curving AAR-2A	Model of Dynamic Curving AAR-1B
Maximum carbody roll angle (degree)	4.0	0.9	1.0
Maximum wheel L/V ratio	0.80	0.52	0.55
Maximum truck-side L/V ratio	0.50	0.28	0.28
Minimum vertical wheel load (%)	25%	52%	60%
Peak-to-peak carbody lateral acceleration (g)	1.3	0.87	0.67
Maximum carbody lateral acceleration (g)	0.75	0.59	0.47
Maximum carbody vertical acceleration (g)	0.90	0.08	0.11
Maximum vertical suspension deflection (%)	95%	23%	34%

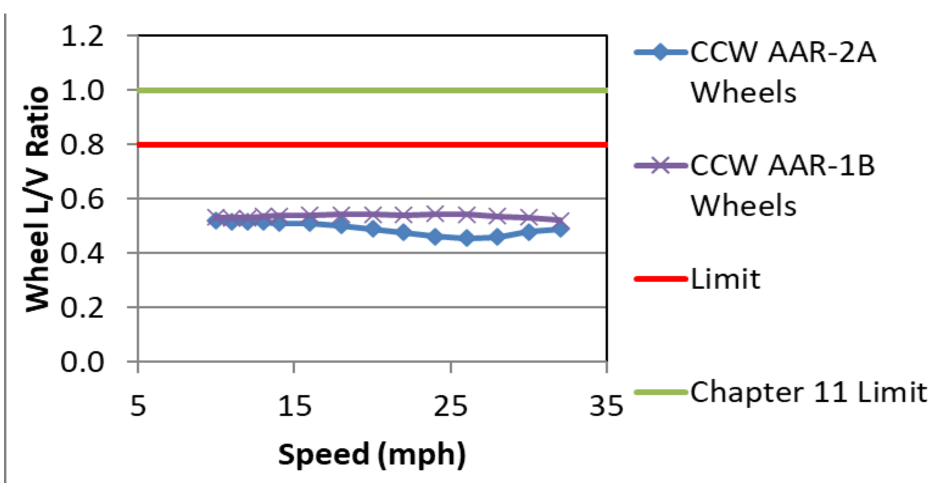

Figure 46. Predicted maximum wheel L/V ratios for the Buffer car in dynamic curving in the CCW direction when equipped with AAR-2A and AAR-1B profile wheels

The model predicts that the Buffer car meets all Standard S-2043 criteria in the dynamic curving regime in both the CW and CCW directions with both AAR-1B and AAR-2A wheel profiles. The AAR-1B profiles are predicted to have somewhat better overall performance in the dynamic curving regime.

7.2 Hunting

Simulations of the hunting regime were conducted according to Standard S-2043, paragraph 4.3.11.3.1 to compare the performance of idealized KR profile wheels with idealized AAR-2A wheel profiles. The KR profile wheels were chosen for the hunting simulations instead of the AAR-1B profile wheels due to the fact that the KR profile wheels represent a slightly worn profile, similar to the AAR-1B after 50,000–100,000 miles of wear, that is more likely to cause hunting in vehicles that have a tendency for lateral instability. Prior to the introduction of the AAR-2A wheel in 2020, Standard S-2043 required KR wheels for hunting tests and simulations. A substitute “worn profile” is not needed for the AA2-2A because the shape of the AAR-2A profile does not change much during initial wear. The simulations were run at speeds from 30 to 75 mph with the KR profile wheels and at 30 to 80 mph with the AAR-2A profile wheels. Speeds for the simulations with AAR-2A profile wheels were increased in 5 mph increments.

Table 34 shows the worst-case simulation predictions for the Buffer car in the hunting regime. The model predicts a slightly higher minimum vertical wheel load and a slightly lower maximum carbody vertical acceleration with the KR wheel profiles.

Figure 47 shows the maximum standard deviation of the carbody lateral acceleration calculated over a sliding 1,000-foot window plotted against speed for the Buffer car. The plot compares the predicted performance of the Buffer car when fitted with wheels having AAR-2A profiles with the predicted performance for the car when fitted with wheels having KR profiles. The models predict that the maximum standard deviation of the carbody lateral acceleration is lower at speeds up to 35 mph when the Buffer car is configured with KR profile wheels. Between the speeds of 40 and 65 mph, the car configured with the AAR-2A profile wheels is predicted to perform better, and from 65 mph on, the KR wheel profiles perform better.

Table 34. Buffer car hunting

Criterion	S-2043 Limiting Value	Model of Hunting AAR-2A	Model of Hunting KR
Maximum carbody roll angle (degree)	4.0	0.4	0.3
Maximum wheel L/V ratio	0.80	0.12	0.12
Maximum truck-side L/V ratio	0.50	0.10	0.10
Minimum vertical wheel load (%)	25%	78%	80%
Peak-to-peak carbody lateral acceleration (g)	1.3	0.35	0.34
Maximum carbody lateral acceleration (g)	0.75	0.19	0.18
Std dev carbody lateral acceleration (g)	0.13	0.07	0.08
Maximum carbody vertical acceleration (g)	0.90	0.25	0.22
Maximum vertical suspension deflection (%)	95%	19%	23%

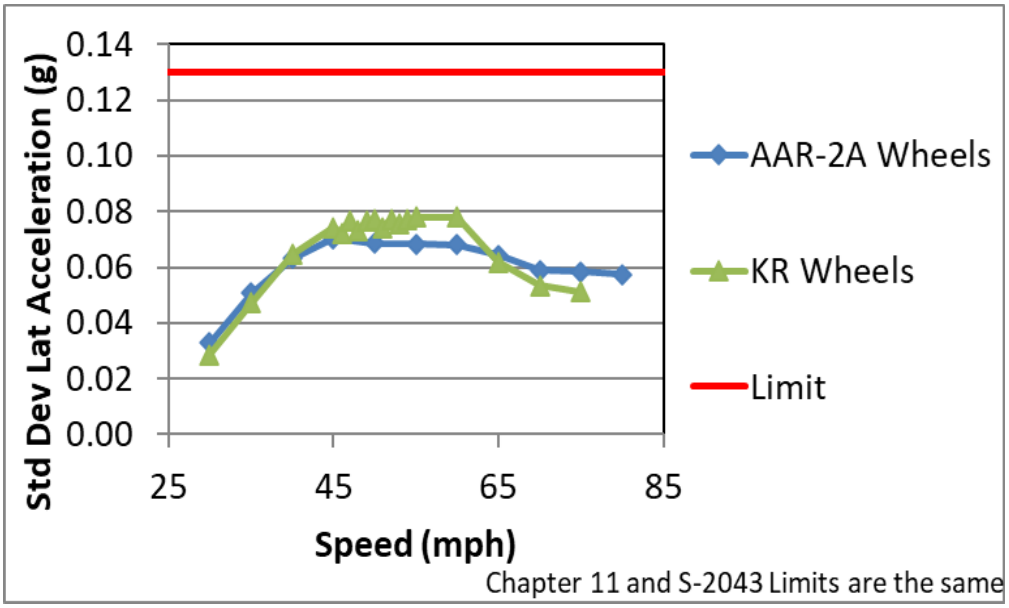

Figure 47. Predicted maximum standard deviation of the carbody lateral acceleration for the Buffer car in hunting when equipped with AAR-2A and AAR-1B profile wheels

The model predicts that the Buffer car will meet all Standard S-2043 criteria in the hunting regime with both the AAR-2A and the KR wheel profiles.

8.0 CONCLUSIONS AND SUMMARIES

The wheel profiles were changed from AAR-1B narrow flange to AAR-2A narrow flange because the AAR-1B produced two-point contact on the ground high rail of the Alps test curve during Standard S-2043, paragraph 6.3.1 tight curve tests in revenue service. The two-point contact reduced axle steering forces and caused poor wheel and truck side L/V ratio performance. This behavior was mitigated by switching to the AAR-2A profile. Both the simulations and test results of Atlas railcar with the minimum test load on the Alps 10-degree curve using the AAR-2A wheel profiles show improved performance over the AAR-1B profiles, especially with respect to the maximum wheel and truck-side L/V ratios (see Figure 5, Figure 6 and Figure 7). The Atlas railcar simulations with the maximum test load on the Alps 10-degree curve with AAR-2A profile wheels also show greatly improved maximum wheel and truck-side L/V ratios compared to the AAR-1B profiles (see Figure 8 and Figure 9). Simulation predictions and results for the test with the REV car show improved truck side L/V ratio performance with AAR-2A profile wheels compared to the AAR-1B profiles (see Figure 10 and Figure 11).

In the other regimes simulated with the AAR-2A profile, the simulation predictions were slightly worse than predictions with the AAR-1B profile for:

- The Atlas railcar with minimum test load in No. 7 crossover (truck side L/V ratio = 0.51with AAR-2A compared to 0.49 with AAR-1B)
    - This difference is very small (only 4 percent)
- The REV in the Class 4 ride quality simulations (standard deviation of lateral acceleration predicted to be 0.14 g with AAR-2A compared to 0.11 g with AAR-1B). Three things

mitigate this concern when considering a change from AAR-1B profiles to AAR-2A profiles:

- The tendency of the model to overpredict carbody lateral acceleration in hunting at speeds below 60 mph (see Figure 19 of reference 6).
- The ability of the onboard monitoring system to monitor and transmit alarms based on carbody lateral acceleration.
- Simulations with the AAR-1B represent a condition that will change quickly in actual service during the initial wear of the AAR-1B wheel profile. After some initial wear the performance of the AAR-1B is likely to be similar to the AAR-2A.

In all other regimes where criteria were not met, simulation predictions were the same or better with the AAR-2A wheel profile. Table 33 through Table 37 show the summary results for the empty Atlas railcar, the Atlas railcar with minimum test load, the Atlas railcar with maximum test load, the REV, and the Buffer railcar.

Table 35. Summary of simulation results for the empty Atlas railcar

Standard S-2043 Section	Met/Not Met	
	Simulations Idealized AAR-1B Wheels (Idealized KR Hunting)	Simulations Idealized AAR-2A Wheels
5.5 Dynamic Tests		
4.3.11.3/5.5.7 Hunting	Met	Met
5.5.10 Dynamic Curving	Met	Met

Table 36. Summary of simulation results for the Atlas railcar with the minimum test load

Standard S-2043 Section	Met/Not Met	
	Simulations Idealized AAR-1B Wheels (Idealized KR Hunting)	Simulations Idealized AAR-2A Wheels
5.5 Dynamic Tests		
Alps 10-degree Curve	Not Met CW Maximum truck side L/V ratio: = 0.74, S-2043 limit = 0.50 CCW Maximum wheel L/V ratio: = 0.81, S-2043 limit = 0.80 CCW Maximum truck side L/V ratio: = 0.75, S-2043 limit = 0.50	Met
4.3.11.3/5.5.7 Hunting	Not Met Std dev carbody lateral acceleration (g): = 0.14, S-2043 limit = 0.13	Met
5.5.10 Dynamic Curving	Met	Met
4.3.11.7/5.5.17 Special Trackwork, No 7 Crossovers	Met	Not Met A-End Leading Maximum truck-side L/V ratio: = 0.51, S-2043 limit = 0.50 B-End Leading Maximum truck-side L/V ratio: = 0.51, S-2043 limit = 0.50

Table 37. Summary of simulation results for the Atlas railcar with the maximum test load

Standard S-2043 Section	Met/Not Met	
	Simulations Idealized AAR-1B Wheels (Idealized KR Hunting)	Simulations Idealized AAR-2A Wheels
5.5 Dynamic Tests		
Alps 10-degree Curve	Not Met CW Maximum truck side L/V ratio: = 0.71, S-2043 limit = 0.50 CCW Maximum truck side L/V ratio: = 0.73, S-2043 limit = 0.50	Met
4.3.11.3/5.5.7 Hunting	Met	Met
5.5.10 Dynamic Curving	Met	Met
4.3.11.7/5.5.17 Special Trackwork, No 7 Crossovers	Met	Met

Table 38. Summary of simulation results for the REV

Standard S-2043 Section	Met/Not Met	
	Simulations Idealized AAR-1B Wheels (Idealized KR Hunting)	Simulations Idealized AAR-2A Wheels
5.5 Dynamic Tests		
4.3.11.3/5.5.7 Hunting	Met	Met
5.5.9 Yaw and Sway	Not Met Peak-to-peak carbody lateral acceleration (g): = 0.83, S-2043 limit = 0.60 Maximum carbody lateral acceleration (g): = 0.53, S-2043 limit = 0.35	Not Met Peak-to-peak carbody lateral acceleration (g): = 0.71, S-2043 limit = 0.60 Maximum carbody lateral acceleration (g): = 0.38, S-2043 limit = 0.35
5.5.10 Dynamic Curving	Met	Met
4.3.10.25.5.15 Curving with Single Rail Perturbation	Met	Met
4.3.11.7/5.5.17 Special Trackwork, No 7 Crossovers	Not Met Maximum truck side L/V ratio: = 0.54, S-2043 limit = 0.50	Not Met Maximum truck side L/V ratio: = 0.54, S-2043 limit = 0.50
4.3.12 Ride Quality	Not Met Class 4 Track: Maximum carbody vertical acceleration (g): = 0.70, S-2043 limit = 0.60	Not Met Class 4 Track: Std dev carbody lateral acceleration (g): = 0.14, S-2043 limit = 0.13 Maximum carbody vertical acceleration (g): = 0.70, S-2043 limit = 0.60

Table 39. Summary of simulation results for the Buffer car

Standard S-2043 Section	Met/Not Met	
	Simulations Idealized AAR-1B Wheels (Idealized KR Hunting)	Simulations Idealized AAR-2A Wheels
5.5 Dynamic Tests		
4.3.11.3/5.5.7 Hunting	Met	Met
5.5.10 Dynamic Curving	Met	Met

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9. ISO 2631-1:1997/Amd 1:2010, Mechanical vibration and shock — Evaluation of human exposure to whole-body vibration.
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Appendix A
EEC Task Force Request for Modeling

From: Nicholas Wilson
Sent: Tuesday, April 4, 2023 12:32 PM
To: Russell Walker; Steven Belport; Jon Hannafious
Subject: REV and ATLAS simulations with AAR2A wheel profile

Per my action item from February EEC S-2043 TAG meeting I reviewed the previous REV and ATLAS reports to see what modeling might need to be rerun with the AAR2A profile (replacing the AAR1b used in the testing and modeling in the reports)

Following are my suggestions for what should be rerun. Basic assumption is that AAR2a has slightly worse conicity and less 2-point contact than AAR1b, so it might improve curving/steering but make hunting/lateral stability worse. My focus is therefore on regimes that were above or near limits for cases where wheelset steering might affect results.

REV Car (report P-21-018)

- Hunting (I think Russ is already doing this?)
- Dynamic Curving (I think Russ is already doing this?)
- ALPS NM test curve (Russ has already done this, and presented extensive results at Feb Tag)
- Curving with single bump:
    - original test result was worse performance than original model with single Wheel L/V right at the 0.8 limit. If new model shows improvement over old model this would suggest that test result would also be likely to improve
- Y&S:
    - Original model and test both exceeded limits. Will exceedances be even larger with AAR2a?
- #7 Crossover:
    - Original model exceeded TSLV – does it get better?
- Worn component simulations:
    - If any of the cases noted above get WORSE with AAR2A, then re-run the corresponding worn component simulation cases also
- Ride quality simulations:
    - Original lateral RQ results rate "uncomfortable" at speeds 40 mph and higher. If hunting gets worse with AAR2a, then re-run the RQ to see how it affects lateral RQ.

ATLAS Car (report P-21-042)

- Hunting (I think Russ is already doing this?)
- Dynamic Curving (I think Russ is already doing this?)
- ALPS NM test curve (Russ has already done this, and presented extensive results at Feb Tag)
- #7 Crossover – Minimum test load (report section 7.11.1):
    - Original model was right at TSLV limit of 0.5, with single wheel L/V just under the limit – does performance get better?
- Worn component simulations:
    - If any of the cases noted above get WORSE with AAR2A, then re-run the corresponding worn component simulation cases also

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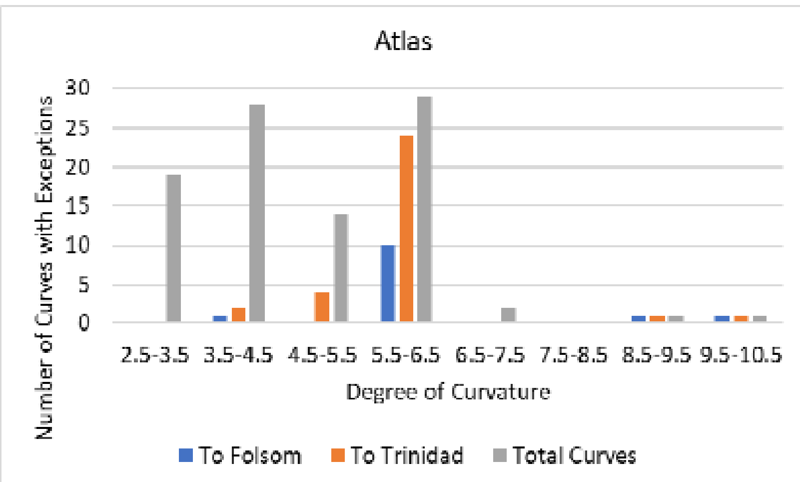
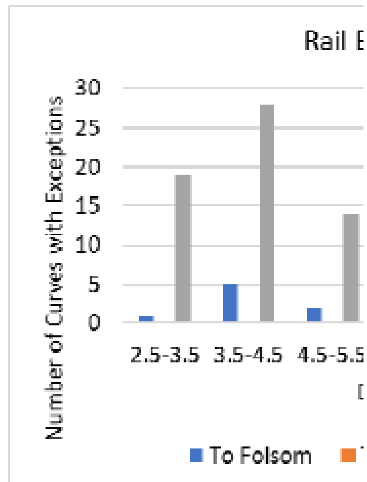
MxV RAIL

From: Russell Walker <russ_walker@aar.com>
Sent: Tuesday, April 4, 2023 10:33 AM
To: Nicholas Wilson <nicholas_wilson@aar.com>
Subject: exception histograms





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